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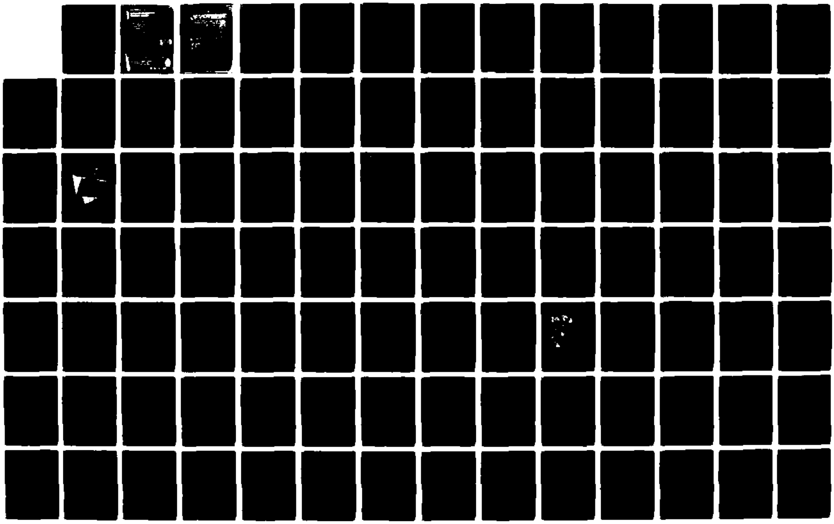

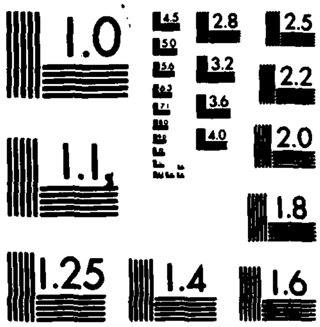

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PAVE PAWS is a new type of surveillance and tracking radar operated by the U.S. Air Force. Its primary purpose is to detect, track, and provide early warning of sea-launched ballistic missiles. The U.S. Air Force has proposed to locate the Southeast PAVE PAWS (SEPP) at Robins Air Force Base, Georgia; an alternate site is Moody Air Force Base, Georgia. Detailed calculations were made to estimate the magnitude and distribution of the radiofrequency radiation (RFR). These calculations indicate that the general public in and around either Robins or Moody Air Force Base would be exposed to average power densities

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20. ABSTRACT (Continued)

that would not exceed 0.002 mW/cm^2. A review of the relevant bioeffect literature indicated that there is no conclusive scientific evidence that chronic exposure to RFR from SEPP outside its exclusion fence would be deleterious to human health. Study and analysis indicated that construction of SEPP would have no significant adverse impacts on the local biophysical environment at either Robins or Moody Air Force Base. The proposed action would result in socioeconomic changes at three locations: the SEPP site and the location of two radar systems to be phased out when SEPP becomes operational--Eglin AFB, Florida, and MacDill AFB, Florida. Significant adverse socioeconomic consequences are not anticipated at any of these sites. The overall conclusion is that the construction and operation of the SEPP at its proposed location on Robins Air Force Base (or Moody Air Force Base) will have no significant environmental impact.

Department of the Air Force
Air Force Systems Command
Electronic Systems Division

SOUTHEAST PAVE PAWS RADAR SYSTEM: ENVIRONMENTAL ASSESSMENT

Houston and Lowndes counties, Georgia

Abstract

This document describes the probable environmental impacts of constructing and operating a new surveillance and tracking radar that would operate between 420 and 450 MHz. The radar would be housed primarily in a single large building on a site of approximately 10 acres. An additional 60 acres would be fenced to limit access in front of the radar. The proposed site for this radar is Robins Air Force Base (AFB); the alternate site is Moody AFB. The impact analysis found that chronic exposure of humans to the radiofrequency radiation levels outside the exclusion fence is not likely to be harmful. No hazards would be associated with fuel handling or cardiac pacemakers at ground level beyond the exclusion fence. Interference with TV reception and other home electronic systems is possible within about 2 miles of the radar. Interference with a UHF land mobile radio repeater is likely at Robins AFB. Electromagnetic interference with amateur radios, radar altimeters, air navigation, and air-ground communication is not likely. No significant adverse biophysical or socioeconomic impacts are expected at either the proposed or alternate site. Construction and operation of the radar system would result in a minor economic boost at either location.

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SUMMARY

SOUTHEAST PAVE PAWS RADAR SYSTEM: ENVIRONMENTAL ASSESSMENT

Description of the Action

PAVE PAWS is a new type of surveillance and tracking radar operated by the U.S. Air Force (USAF). The primary mission of the PAVE PAWS system is to provide warning and characterization of a sea-launched ballistic missile (SLBM) attack against the continental United States, Alaska, and southern Canada. The secondary mission is to provide warning and characterization of an intercontinental ballistic missile (ICBM) attack against the above areas. The system has a collateral mission to augment the North American Aerospace Defense Command's Space Detection and Tracking System (SPADATS).

The Air Force is proposing to locate the Southeast PAVE PAWS (SEPP) at Robins Air Force Base (AFB), Georgia. An alternate site at Moody AFB has also been identified. Two other similar radar systems are already operating, one at Otis Air National Guard (ANG) Base in Massachusetts and the second at Beale AFB in California. A fourth PAVE PAWS has been proposed for the vicinity of Goodfellow AFB in Texas. If SEPP becomes operational, older radars at Eglin and MacDill AFBs in Florida will be retired. SEPP is expected to operate continuously for at least 10 years.

SEPP would be housed in a large main building with associated facilities on a site of approximately 10 acres. An additional 60 acres would be fenced and posted to prevent humans and large animals from approaching close to the radar faces. Approximately 234 operating and maintenance personnel would be required. Deactivation of the radars to be replaced would reduce manpower requirements at Eglin and MacDill AFBs by a total of 450 positions.

Radiofrequency Radiation

Detailed calculations were made to estimate the magnitude and distribution of the radiofrequency radiation (RFR) from SEPP, and the resulting values were used to estimate the effects, if any, of RFR. The validity of the computational methods had already been demonstrated by comparing field measurements to similarly calculated values for the PAVE PAWS system at Beale AFB.

People who are airborne in the surveillance volume of SEPP may be exposed to the main beam for brief intervals. In the enhanced surveillance mode, which represents a worst case, the calculated average power density will be about 3 mW/cm^2 at 1,850 ft (the approximate boundary between the near- and far-field regions) and about 0.4 mW/cm^2 at

1 mile. Within 1,850 ft, the average power density will not exceed 57 mW/cm^2. The pulse power density beyond this distance will be less than 900 mW/cm^2 and will not exceed this value for smaller distances. These values for airborne exposure are applicable to both the Robins and Moody AFB sites.

Calculations indicate that under no circumstance would the general public be exposed to average power densities at ground level in excess of 0.1 mW/cm^2, which is the maximum value just outside the exclusion fence of the radar. Locations likely to be occupied by substantial numbers of people would be subject to lower values of RFR. At the south shore of Luna Lake (Robins AFB), the calculated average power density is 0.014 mW/cm^2. At a building near U.S. Highway 221 (Moody AFB), the value is 0.045 mW/cm^2. Calculated average power densities at all other population centers are substantially smaller. These values do not include attenuation due to the presence of foliage. At Robins AFB, the area outside the exclusion fence is heavily wooded, which would reduce the above values at least tenfold. At the Moody AFB site, the local foliage is less dense, but the site is remote from human habitation.

In the standard recently adopted by the American National Standards Institute (ANSI), the maximum permissible average power densities for human exposure for the 420 to 450 MHz range are 1.4-1.5 mW/cm^2. The average power densities at ground level just outside the exclusion fence would be more than order of magnitude lower (i.e., more than 10 times smaller) than these new ANSI values. In addition, values in the population centers near either site would be lower than the new USSR standard of 0.01 mW/cm^2 for general population exposure.

Environmental Effects

Human Health

Because radiation safety is of paramount importance, an in-depth, critical review of the available literature on the biological effects of RFR was carried out. This review will serve as the primary reference for the human health aspects of this environmental assessment for SEPP as well as statements for other proposed Air Force RFR-emitting systems. The review does not include any system-specific information; rather, it addresses the present state of scientific knowledge regarding the biological effects of RFR in the range from 0 to 300 GHz. The most pertinent and scientifically significant research results in the review were used to derive conclusions regarding possible RFR bioefffects of SEPP.

Collectively, the results of the relatively few epidemiologic studies performed in the United States, the USSR, and other Eastern European countries are not regarded as evidence that environmental levels of RFR are likely to constitute a hazard to the general population.

Most U.S. experiments with animals that yielded recognizable and repeatable effects of exposure to RFR were performed at incident average power densities of more than about 2 mW/cm^2. Such effects are thermal

in the sense that the RFR energy is absorbed by the organism as widely distributed heat that increases the whole-body temperature, or as internally localised heat that is biologically significant even with natural heat-exchange and thermoregulatory mechanisms operating.

The existence of threshold values of average power density has been experimentally demonstrated for some effects and postulated for others. Exposure to RFR at average power densities exceeding the threshold for a specific effect, for a few minutes to a few hours (depending on the value), may or may not cause irreversible tissue alterations. The heat produced by indefinitely long or chronic exposures at power densities well below the threshold is not accumulated because its rate of production is readily compensated for by heat-exchange processes or thermoregulation.

Most investigations involving chronic exposures of mammals yielded either no effects or reversible, noncumulative behavioral or physiological effects for average power densities exceeding 2 mW/cm^2. In the few cases in which irreversible adverse effects of exposure were found, such effects were absent for average power densities below 2 mW/cm^2.

In a relatively small number of investigations, biological effects of RFR were reported at incident average power densities less than about 2 mW/cm^2. Such effects have been called "nonthermal," to distinguish them from those mentioned above. However, this usage of nonthermal is confusing and imprecise because the interaction mechanisms involved in each such effect differ considerably from those for the other effects, and clear distinctions between thermal and nonthermal effects based on precise scientific definitions of these terms are difficult to discern in the interactions.

The detection of individual RFR pulses as apparent sound has been characterized as nonthermal, primarily on the basis that the average power density would be minuscule if the time intervals between consecutive pulses were large. However, the average power density is not relevant, because the interactions that produce the effect are dependent primarily on the characteristics of individual pulses.

In sum, the review of the relevant literature indicates that there is no reliable scientific evidence to suggest that chronic exposure to the RFR from SEPP outside the exclusion fence will be deleterious to the health of even the most susceptible members of the population such as the unborn, infirm, or aged.

<u>Electromagnetic Interference and Hazard Effects</u>

SEPP is authorized to operate in the band between 420 and 450 MHz, and only a small amount of energy is expected to fall outside this band. The band is set aside principally for government use and is shared with other military radar systems, including the other PAVE PAWS radars, radar altimeters, and other systems, any of which could produce mutual interference if close enough. Any such problems would be resolved within the

military. The Amateur Radio Service is also permitted to use this band, but on a noninterference basis and without recourse if interfered with by the government radars. The amateurs and the PAVE PAWS radars use the band cooperatively in other geographic regions and can be expected to do so in Georgia.

Experience has shown that the possibility of interference to civilian and government land mobile radio systems, which occupy the spectrum just above and below the PAVE PAWS band, is generally not high. However, interference with a land mobile repeater system operated by Georgia Power Company is probable; it is less than 2 miles from the SEPP site at Robins AFB. The USAF will work with Georgia Power Company to identify the nature and extent of any problems and will develop mitigating measures. No similarly vulnerable land mobile systems were found in the vicinity of the SEPP site at Moody AFB.

Some interference to TV reception is likely in areas within a few miles in front of SEPP. There are not many residences in such locations near Robins or Moody AFB. Some types of TV interference can easily be eliminated by using an Air-Force-provided filter.

Air navigation systems and air-to-ground communication systems are not expected to be affected by SEPP at either site.

Potential hazard effects were also considered. SEPP would not be a threat to fuel-handling operations or to ground-based electroexplosive devices at either Air Force base. Neither would it be a threat to cardiac pacemaker owners on the ground outside the exclusion fence at either site.

Biophysical Effects

The proposed SEPP site at Robins AFB is a pine-hardwood forest designated as both a recreational and a timber-management area that was cultivated for agriculture until approximately 25 years ago. A floodplain and a lowland swamp are adjacent to the site. No evidence of threatened or endangered plant or animal species was found in the immediate area. In particular, no red-cockaded woodpecker cavity trees were discovered.

Construction of SEPP would have no significant adverse impact on the local biophysical environment at Robins AFB. However, approximately 18 acres of habitat would be destroyed, and another 60 acres within the perimeter fence would become inaccessible to large animals. A network of nature trails in the existing recreation portion of the base would be disturbed, a problem that could be mitigated by providing new trails north of the site and of the Nature Center in the Unique Natural Area. Sufficient groundwater is available in the local aquifer to supply the site. For the most part, the air emissions, noise, and water effluent created by construction and operation of the project would be minor compared to that currently generated by base activities, although emissions of nitrogen oxides and sulfur oxides could be noticeable. The Robins AFB

sewage treatment plant is overloaded during extremely wet weather, although average flow at the plant is well below capacity. Because wastewater from SEPP would add to periodic overflows at the plant, base engineers are planning to modify the facility. The area has experienced sporadic earthquakes, tornadoes, and floods; therefore, the radar building should be built to withstand such natural disasters.

The proposed SEPP site at Moody AFB is an abandoned airfield included within a federal game management area. The site contains no threatened or endangered plant or animal species. Locating SEPP at the airfield site would not have significant adverse impacts on the local biophysical environment. Water requirements could probably be satisfied by a new well at the site with minimal effect on the water table. Neither particulate, hydrocarbon, and carbon monoxide emissions nor noise would be significant; sulfur oxide and nitrogen oxide emissions could be noticeable. Wastewater could be accommodated at the base sewage treatment facility or by a small package plant at the site. Because the area is swampy and prone to flooding, some precautions would be required to provide adequate drainage as well as to prevent surface and groundwater contamination.

Socioeconomic Effects

The proposed action would result in socioeconomic change at three locations: the SEPP site and the locations of the radar systems that would be phased out--Eglin AFB and MacDill AFB. Significant adverse socioeconomic consequences are not anticipated at any of these sites.

The construction and operation of SEPP would provide a minor economic boost to the Robins AFB region. In absolute terms the boost would be about the same in the Moody AFB region; however, because the Robins AFB region is larger, the relative boost would be greater in the Moody AFB region. The change in employment and spending in either local area would be substantially greater during operation than construction. Operation of the system would generate approximately 360 new jobs (including USAF personnel) and increase the population in either region by about 600. The change would occur over an 18-month period in 1984 and 1985 and would not adversely tax local private and public facilities and services. Although rental housing currently is not plentiful in the Warner Robins or Valdosta areas, current building trends in each area indicate that sufficient housing stock should be available to meet the requirements of USAF personnel.

Closure of the MacDill AFB radar facility would have no adverse effects on the local economy. The base is preparing several hundred new positions, so the loss of 60 radar-related authorizations would not be felt. Furthermore, the base is located in a large and growing urban area.

Phaseout of the radar facility at Eglin AFB would also cause no significant socioecon[illegible]ic effect[illegible] The proposed action would reduce USAF employment by about 3[illegible] [illegible] 19[illegible] [illegible]n a region with a current population of

123,000. The population at the base is expected to be otherwise constant in the mid-1980s, and the local economy is growing.

A literature search and subsequent cultural resource field survey of the proposed SEPP location on Robins AFB revealed a potentially important archeologic site at the edge of the radar safety zone. The importance of the site and its eligibility for the National Register of Historic Places cannot be determined unless a test excavation is conducted. Rather than excavate the site or disturb it in any way, the Air Force has chosen to include the entire site within the perimeter fence of the SEPP project. Thus, the archeologic site would not be adversely affected and would be preserved intact during the lifetime of the radar facility. A cultural-resource survey determined that no archeologic sites would be affected if SEPP were located at Moody AFB.

Alternatives Considered

No Action

SEPP would not be constructed and operated at either Robins or Moody AFB, and radars that SEPP is scheduled to replace would continue operating.

Postpone Action

Construction and operation of SEPP would be postponed to allow resolution of specific problems or issues related to PAVE PAWS operation.

Different Location

A site at Moody AFB was considered as an alternate to the preferred location at Robins AFB.

Conclusion

Operating SEPP at its proposed location on Robins AFB or at the alternate site on Moody AFB would have no significant environmental impact.

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ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Concluded)

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TABLES (Continued)

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1 PURPOSE AND NEED FOR ACTION

PAVE PAWS is a surveillance and tracking radar system operated by the U.S. Air Force (USAF). The primary purpose of this radar is to detect, track, and provide early warning of ballistic missiles launched at sea against the continental United States. Detection and warning of a sea-launched ballistic missile (SLBM) attack is currently provided by two PAVE PAWS radars located at Otis Air National Guard (ANG) Base, Massachusetts, and Beale Air Force Base (AFB), California; the Perimeter Acquisition Radar Attack Characterization System (PARCS) in North Dakota; the AN/FPS-85 phased array radar at Eglin AFB, Florida; and the AN/FSS-7 radar at MacDill AFB, Florida.

Two additional PAVE PAWS radars are needed to complete coverage of the ocean areas from which SLBM attacks might be launched, one in the southeastern and one in the southwestern United States. A secondary purpose of the Southeast PAVE PAWS (SEPP) is to complement the Space Detection and Tracking System by tracking satellites and other objects in near-earth orbits.

2 PROPOSED ACTION AND ALTERNATIVES

2.1 Proposed Action

The proposed action consists of constructing and operating a PAVE PAWS radar system at Robins AFB, Georgia. Once SEPP is operational, radars at Eglin and MacDill AFBs, Florida, will be deactivated. Moody AFB, Georgia, has been identified as an alternate location for SEPP (see Figure 2-1). The proposed action, the preferred location, and the alternate location are described in the following sections. No action or postponement of the action are the only other alternatives considered in this document.

2.1.1 The PAVE PAWS Radar System

The SEPP radar system is one of a projected set of four similar radars in the United States. Their military designation is AN/FPS-115; the name PAVE PAWS combines a designation for electronic systems and an acronym standing for phased array warning system.

Two PAVE PAWS radar systems have already been built and are now operating at Otis ANG Base on Cape Cod in Massachusetts and at Beale AFB near Sacramento, California. Another system, identical to those now operating, is projected for construction near Goodfellow AFB in San Angelo, Texas.

The PAVE PAWS system differs from conventional rotating dish radars in that the antenna is stationary and consists of two flat arrays of many individual radiating elements called dipoles. All PAVE PAWS systems have the same number of dipoles, and all use identical radiating elements. The principal difference between the various installations is the number of amplifiers used. In SEPP, an amplifier will be provided for each dipole; other radars use only one-third as many amplifiers, leaving the other dipoles passive.

Most of SEPP will be contained in a building 105 ft high and approximately 100 ft by 150 ft at its base (see Figure 2-2). Five floors of the building will house radar equipment, maintenance areas, office space, and a cafeteria. Figure 2-3 shows other facilities on the approximately 10-acre site, including an access road, parking areas, a gatehouse, fuel storage, fencing, and utilities (i.e., facilities for water supply and distribution and electric power generation and distribution). Many support facilities such as a sewage treatment plant and staff housing already exist at Robins AFB.

A zone extending about 1,000 ft in front of the radar will be fenced (8-ft, chain-link exclusion fence) and posted to prevent humans and large animals from inadvertently approaching too close to the radar faces. A security fence (8-ft, chain-link with barbed wire) 200 ft from the radar will surround the buildings and other facilities. A perimeter detection system, located near the security fence, will signal the

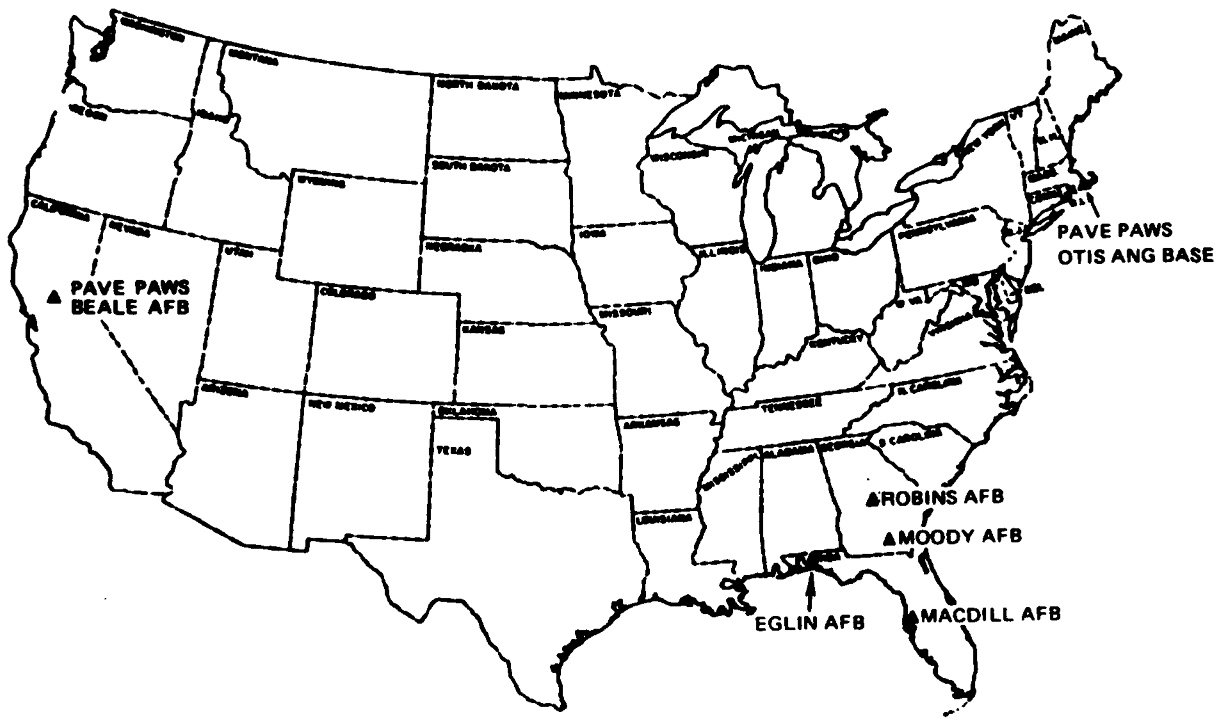
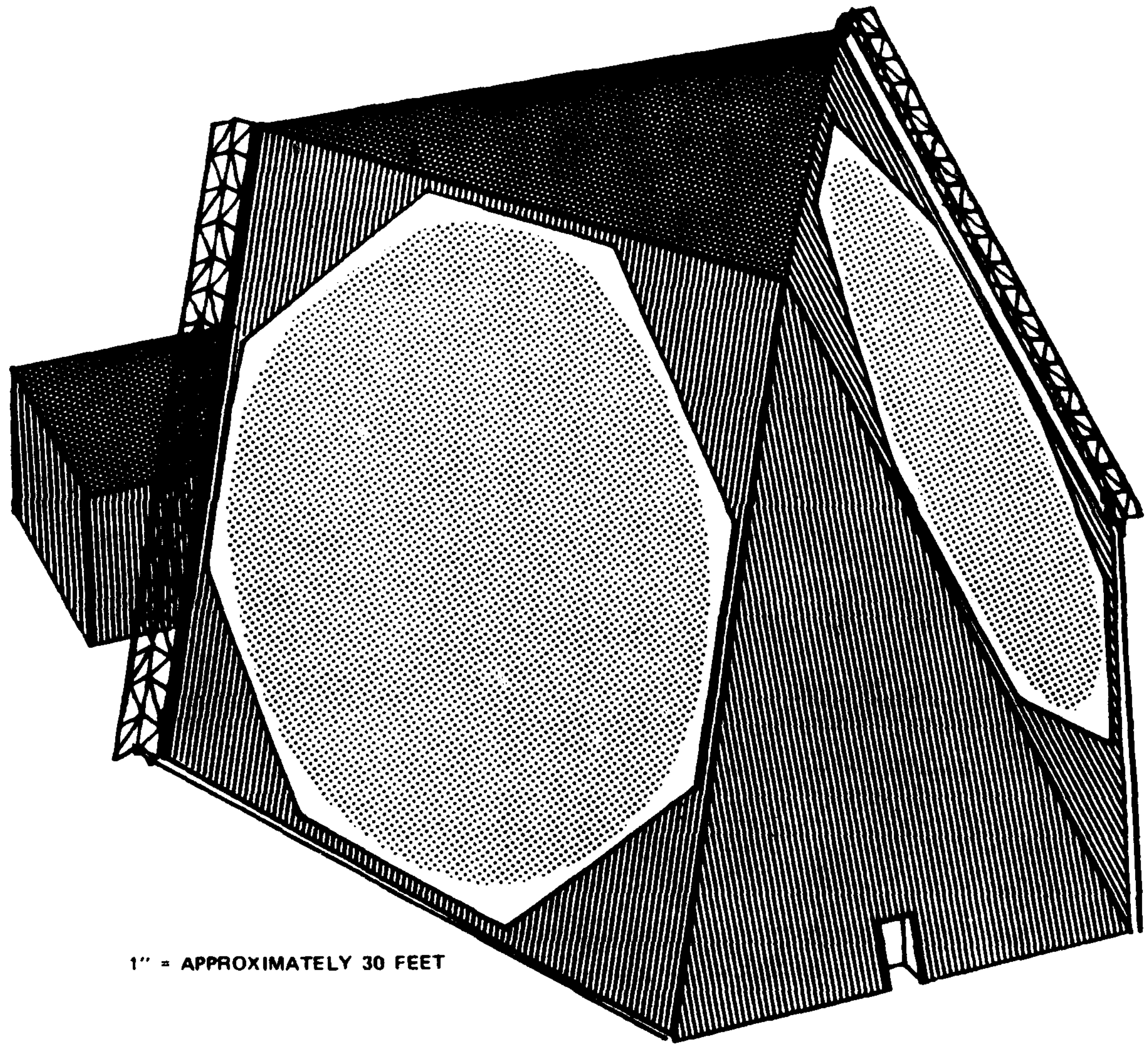


FIGURE 2-1 EXISTING PAVE PAWS SITES AND LOCATIONS OF PROPOSED OR ALTERNATE SEPP ACTION



1" = APPROXIMATELY 30 FEET

FIGURE 2-2 PAVE PAWS RADAR AND POWER PLANT BUILDINGS

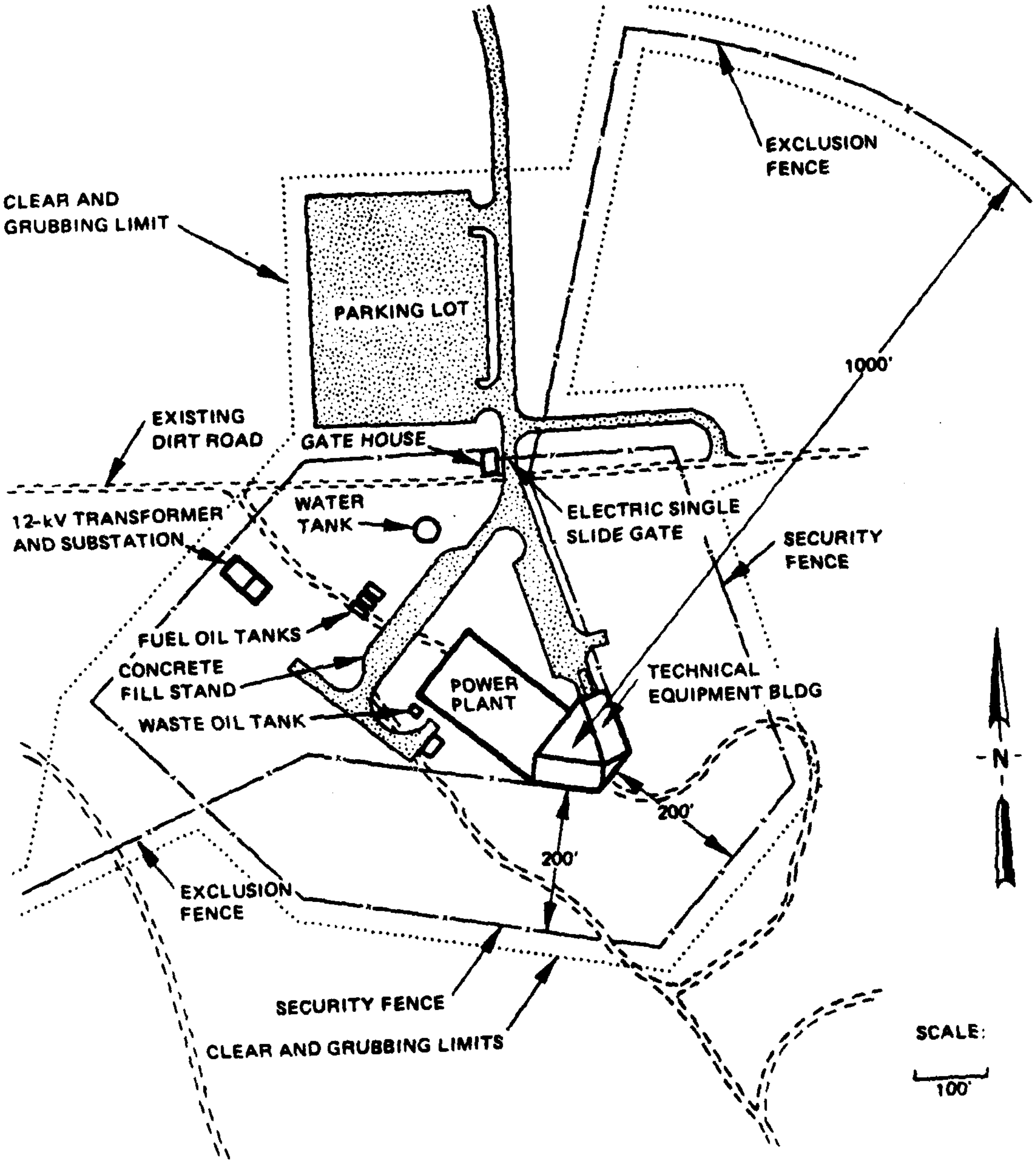


FIGURE 2–3 PROPOSED SITE PLAN FOR PAVE PAWS

presence of any intruder to the guards. The entire site will occupy less than 100 acres.

Current plans call for SEPP to operate continuously for 10 to 20 yr, with normal operations beginning in 1986. An estimated 234 operating and maintenance personnel will be required, 14 of whom will be civilian employees. This total includes administrative and management personnel as well as technical staff for three shifts. An additional 29 base operating and support personnel will be assigned to Robins AFB to support the SEPP mission and personnel.

As shown in Figure 2-2, the main building is roughly triangular in shape. Instead of a rotating dish-shaped antenna, PAVE PAWS has two flat antenna arrays that make up two walls of the main building. The two walls form a 60-deg angle and are tilted back 20 deg from the vertical. When the system is operating, each antenna array forms an electromagnetic beam.

Each array is composed of 5,376 individual antenna elements, all of which will be electrically activated. During operation, a prescribed electric current delivered to those elements generates local electric and magnetic fields. Spreading and merging of the fields from the many elements creates the radar beam. The radar may operate at any of 24 specific frequencies between 420 and 450 megahertz (MHz). By way of reference, this band (shared with the radio amateurs) is located just below the frequency bands used in such mobile land communication systems as fire, police, and taxi radios.

Each antenna array broadcasts radiofrequency radiation (RFR) throughout a portion of a hemisphere centered on the array face (see Appendix A for a detailed description). Two RFR regions with distinct characteristics are created: (1) the near field, less than about 1,850 ft from the antenna array; and (2) the far field, beyond about 1,850 ft.

The RFR environment in both regions is very complicated, but its important features can be described simply. In the near field, nearly all of the radiated power appears in a well-defined, approximately cylindrical portion of the hemisphere.

Over a lengthy transition zone, the RFR field evolves into a pattern that in the far field resembles a set of cones. The main beam occupies the innermost cone within 1.5 deg of the direction in which it is aimed (see Figure 2-4 and Figure A-1). The remainder of the hemisphere contains sidelobes, the first three of which occupy a set of hollow cones centered on the main beam (see Figure 2-4). The higher order sidelobes are irregularly shaped cones distributed in a pseudorandom fashion throughout the hemisphere.

In the far field, about 77% of the radiated power is concentrated in the main radar beam; the remainder appears in the sidelobes. The power density of the sidelobes is at most 1/40th (first sidelobe) to 1/1000th (higher order sidelobes) of the main-beam power density.

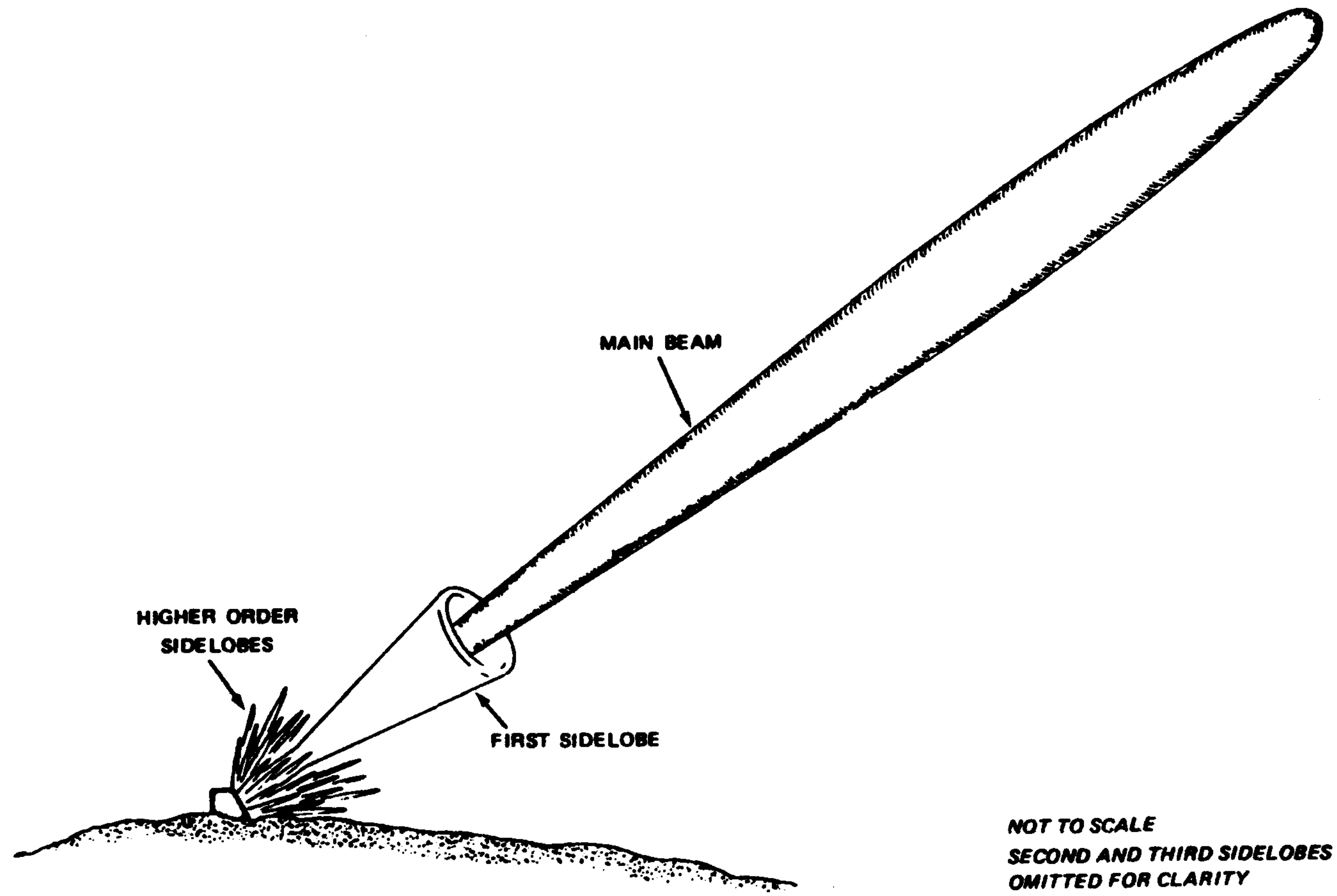


FIGURE 2-4 ARTIST'S SKETCH OF PAVE PAWS RFR PATTERN

Because power densities relatively few degrees away from the beam axis are such small fractions of the main beam power density, the PAVE PAWS radar beam is functionally a highly focused, narrow beam of radiation.

Neither the main beam nor the sidelobes radiated by each antenna array occupies the entire hemispheric volume at all times. The radar beam is actually a series of electromagnetic pulses whose characteristics are prescribed by surveillance and tracking requirements. Thus, the beam is intermittent rather than continuous. PAVE PAWS will transmit only about 15% of the time and will receive reflected RFR during the remaining 85% (see Section A.3 for a detailed description).

Each radar beam can be "steered" or pointed electronically from 3 deg to 85 deg above the horizontal. It can also be steered as much as 60 deg to the left or right (that is, ± 60 deg in azimuth), for a total of 240 deg of azimuthal coverage by the two antenna arrays (see Section A.2.3). The radar beams can search for or track objects as much as 4,000 nautical miles away.

To detect SLBMs, the radar beams will scan continuously through their azimuthal range at 3 deg above the horizontal (although the scanning elevation may occasionally be raised to as much as 10 deg above the horizontal). One antenna face will point east-northeast and the other south-southwest. Scanning will range clockwise from 10 to 250 deg by the compass, or roughly from east of north, to east, to south, to south of west.

For satellite or missile tracking, the radar beams will be pointed as much as 85 deg above the horizontal. The scanning action of the radar beams will be so rapid that any given point will be "in" the main beam for only a fraction of a second at about 1.4-s intervals. However, points not in the main beams will be exposed to the low-level sidelobe RFR during each pulse.

2.1.2 Proposed Location: Robins AFB

The proposed location for the construction and operation of SEPP is Robins AFB, in central Georgia about 90 miles southeast of Atlanta and 20 miles south of Macon (see Figure 2-5). The City of Warner Robins is adjacent to the base. Robins AFB is a large, sprawling installation occupied by more than 30 organizations with diverse missions. The largest organization is the Warner Robins Air Logistics Center (WR-ALC). Other major units are the Headquarters Air Force Reserve, 5th Combat Communications Group, 1926 Communications and Installation Group, and the 19th Bombardment Wing.

WR-ALC is one of five units of the Air Force Logistics Command that provide logistics support to the U.S. Air Force. It determines the spare parts, supplies, and equipment needed to support the weapons systems for which it is responsible. It budgets for, buys, stores, distributes, repairs, maintains, and disposes of these systems. Moreover, it is system manager for 24 aircraft, 8 missiles, and 18 support

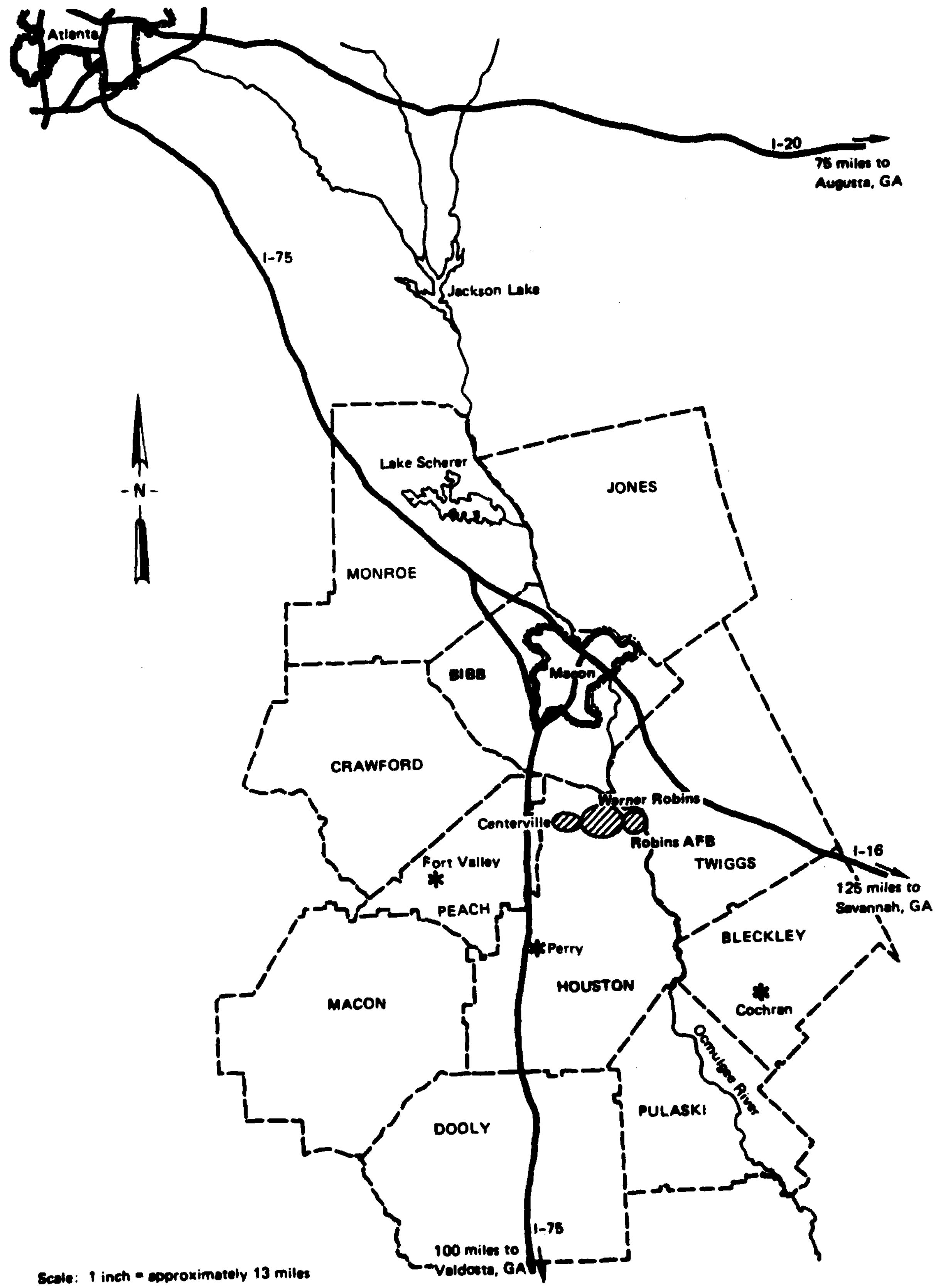


FIGURE 2-5 ROBINS AIR FORCE BASE REGION

systems, as well as a repair center for its assigned aircraft, airborne electronics, and other equipment. Thus, most workers at WR-ALC are engaged in repairing, modifying, and overhauling aircraft and equipment. Finally, WR-ALC is a storage center--receiving, storing, issuing, and transferring spare parts and systems.

Robins' 8,809 acres of land have a variety of designated land uses, including administrative, warehousing, industrial, community areas, housing, and flying operations. Only 1,153 acres are improved, primarily because various planning restraints limit the amount of developable land. This lack of development has created an isolated location suitable for SEPP.

The proposed SEPP site is located in a heavily wooded area very near the southeast corner of the installation (83° 34' 09" W longitude and 32° 34' 49" N latitude). The site's virtues include its undeveloped state, its remoteness from populated areas off base, and its nearness to a commercial power source. Other possible locations on or near the base were eliminated because they were too close to the runway, populated areas, or the avionics repair center. More descriptive information, including base and site maps, can be found in Section 3.1.

2.1.3 Deactivation of Obsolete Radar Systems

Operation of SEPP will make it possible to close two currently operating radar systems, one at Eglin AFB and the other at MacDill AFB, both in Florida. Additional information on these bases appears in Sections 3.3 and 3.4.

2.1.3.1 Eglin AFB

Eglin AFB is located in northwestern Florida, north of Fort Walton Beach and east of Pensacola. It contains 463,000 acres of land in three counties and stretches 51 miles east to west and 19 miles north to south. On the south it is adjacent to Choctawhatchee Bay and the Gulf of Mexico.

When SEPP goes into operation, an AN/FPS-85 phased array radar at Eglin will be deactivated. Located in the eastern part of Eglin AFB, this radar (operated by the 20th Missile Warning Squadron) was originally designed specifically to detect and track satellites. Later, the capability to detect and provide early warning of an SLBM attack was added. This is now the radar's primary mission, although it tracks 80% of all objects in earth orbit. It also serves as an alternate computation center for the Space Defense Operations Center.

2.1.3.2 MacDill AFB

MacDill AFB occupies the tip of the Interbay Penninsula, which juts into Tampa Bay. Its major function is to serve as a base for training fighter pilots and weapons systems officers.

SEPP will replace the existing AN/FSS-7 radar, located in an undeveloped portion of the base, which carries out a missile warning mission.

2.2 Alternate Site: Moody AFB

The Air Force has identified Moody AFB as the alternate location for SEPP. Moody is located in south central Georgia, about 20 miles northeast of Valdosta, Georgia, and 35 miles north of the Florida border (see Figure 2-6). It is the home of the 347th Tactical Fighter Wing, which flies tactical fighter missions to destroy enemy forces and equipment.

The specific alternate site is an abandoned auxiliary airfield (83° 03' 49" W longitude and 30° 56' 56" N latitude). This site was selected because it is southeast of the main base, on federally owned land or land committed to exclusive use by the Air Force, in a cleared area, not adjacent to populated areas, and near commercial power. Other possible sites were ruled out because they were north or northwest of the base or in swampy or open-water terrain. More detailed information is given in Section 3.2.

2.3 No Action or Postponement of Action

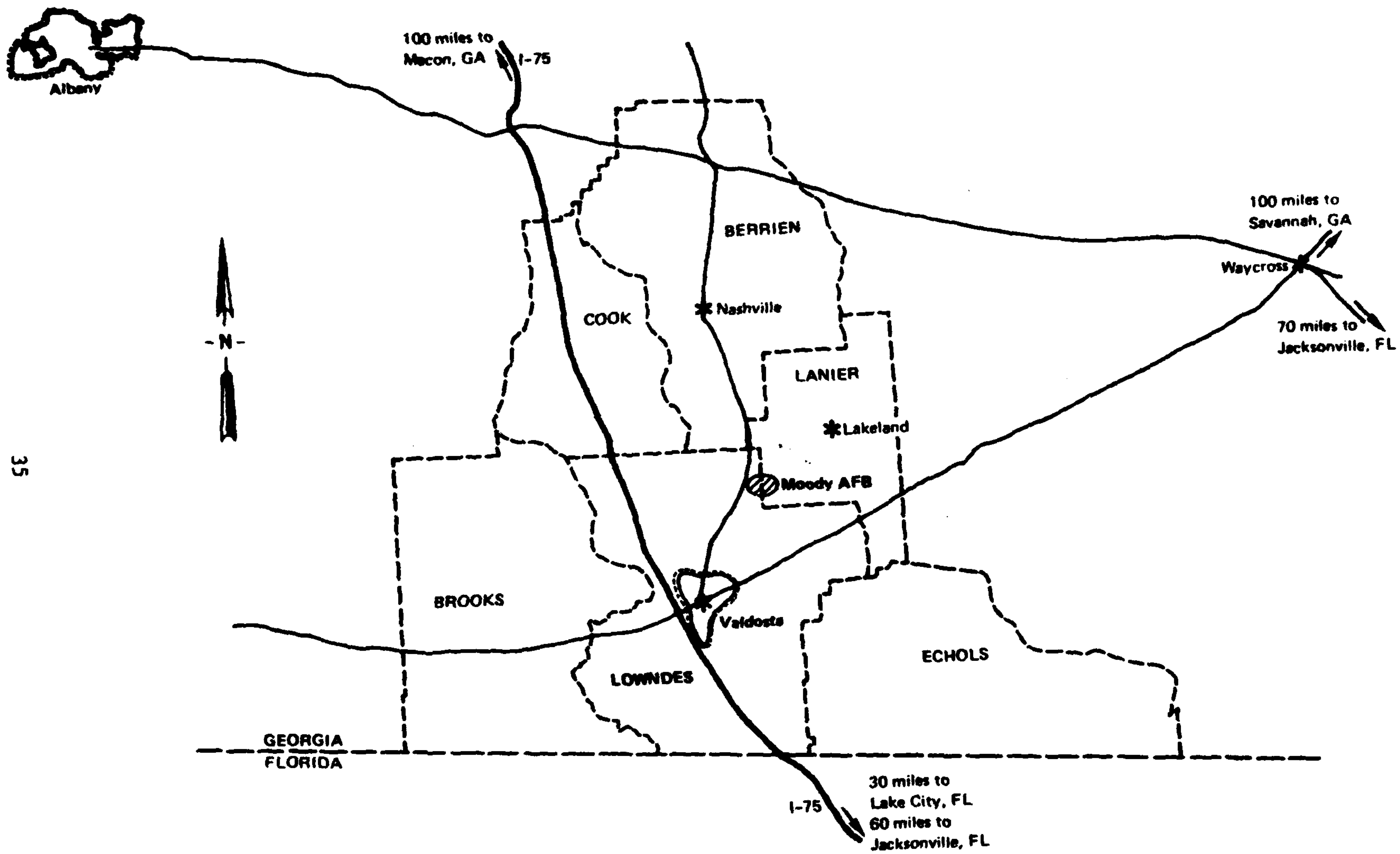
The no-action alternative is not to construct and operate a SEPP, either at Robins or Moody AFB. If SEPP were not constructed and operated, the older radars that it is scheduled to replace would continue to operate. No alternative means of radar surveillance and tracking will be available in the foreseeable future to substitute for PAVE PAWS. From this point of view, postponing construction and operation of SEPP is equivalent to the no-action alternative until the decision is made to go ahead. Consequently, because the nature of the threat from SLBMs has made the existing radars obsolete, changes in defensive military strategies, and possibly national policies, might become necessary to compensate for the lack of information characterizing an attack.

2.4 Alternatives Eliminated

Robins and Moody AFBs emerged as the preferred and alternate locations for SEPP on the basis of site selection criteria developed jointly by the Electronic Systems Division, the Strategic Air Command, the Aerospace Defense Center, and the Headquarters of the U.S. Air Force. They are as follows:

(1) Maximize the coverage of potential launch areas for SLBMs.

(2) Minimize the threat of electromagnetic countermeasures by locating SEPP sufficiently inland to preclude jamming by surface vessels.



Scale: 1 inch = approximately 13 miles

FIGURE 2-6 MOODY AIR FORCE BASE REGION

(3) Minimize electromagnetic interference with military and civilian electronic transmitters and receivers.

(4) Provide an unobstructed view over all 240 deg of azimuth coverage.

(5) Avoid proximity to either airfields or major roads to preclude the accidental activation of electroexplosive devices.

(6) Minimize human exposure to RFR by avoiding populated areas, particularly in the direction of the radiated energy.

(7) Use available land in the following order of preference: military, other federal, state, local, private.

(8) Ensure visibility of a Defense Satellite Communication System satellite for timely communication.

(9) Locate on or near an active military installation.

(10) Consider base support, base communication, commercial power, fire protection, soil composition, water supply, wastewater treatment, construction labor force, rail siding, community support, and environmentally sensitive areas.

The first, seventh, and ninth criteria were key to the selection of Robins and Moody AFBs. Application of the first criterion defines an area about 140 miles long by 80 to 100 miles wide centered on Robins and Moody. Within that area, these two bases are the obvious choices that also satisfy the other criteria. Because of the readily apparent suitability of these two bases, especially Robins AFB, coupled with the absence of other obvious candidates, no other alternate sites were identified for consideration. For environmental, mission, and other considerations, Robins AFB became the preferred site.

3 AFFECTED ENVIRONMENT

3.1 Robins AFB (Proposed Site)

3.1.1 Biophysical Environment

3.1.1.1 Electromagnetic Environment

The electromagnetic environment at a particular location and time comprises all the electromagnetic fields that arrive there from numerous sources, both man-made and natural. Some of these fields are used for communication purposes or for radiolocation (radar). The electromagnetic spectrum in the area is a renewable resource having the dimensions of amplitude, time, frequency, and space. It can be used continuously. In areas large enough to permit sufficient geographical separation, the spectrum will accommodate a number of users on the same frequency simultaneously. In smaller areas the spectrum will accommodate a large number of users only if the frequencies that are used are separated. A high-amplitude signal can mask a low-amplitude signal on the same frequency.

The electromagnetic environment at a point can change almost instantaneously, and, at a given instant, it will not be the same at two points a few feet away. Therefore, it is generally convenient to deal with averages over time and space. When there is sufficient incentive, certain features of the electromagnetic environment can be measured and documented. However, because of the cost, attempts are seldom if ever made to define the electromagnetic environment simultaneously over wide frequency ranges, large geographical areas, and long time durations.

Some of the man-made contributions to the electromagnetic environment in the vicinity of Robins AFB are intentional, but others are accidental, and are incidental to some other activity. Radio signals of all sorts are intentional man-made contributions. The electromagnetic environment in the area consists in part of signals from the following: various broadcast radio and TV stations at least as far away as Atlanta; radios of local law enforcement and fire departments and other users of land mobile radio; local or transient amateur and CB operators; microwave communication systems of the telephone company, the Georgia Power Company, and the cable TV company; air navigation aids; passing aircraft; satellites that provide the cable TV programming; and others. Because some signals, much lower in frequency than PAVE PAWS, can be reflected back to earth by high-altitude ionospheric layers, part of the electromagnetic environment in the area consists of transmissions from stations thousands of miles away.

The unintentional man-made contributions to the electromagnetic environment in the area are called man-made electromagnetic noise. Such noise is radiated by power lines, fluorescent lights, household lighting dimmer switches, household appliance motors, computers, hand-held calculators, and so on. A major contributor is the automobile ignition

system, which radiates a pulse of energy over all the communication bands with each spark-plug firing.

Nature contributes only noise to the electromagnetic environment. Even when there are no local thunderstorms, lightning strokes in storm centers in Africa and South America can cause "static" in radios in Georgia, thousands of miles away. This noise is an intermittent major feature of part of the area's electromagnetic spectrum. In some parts of the electromagnetic spectrum, noise from the sun and from the stars (galactic noise) is often the predominant feature of the local electromagnetic environment.

Human beings are not generally capable of sensing the electromagnetic environment or changes in it, although radio receivers regularly do this. They sample portions of the spectrum to extract a small amount of energy, which they then amplify and convert to a usable signal. This signal might be in the form of a picture on channel 13 from Macon, music from WRBN, a long-distance telephone conversation, an air navigation signal, or many others.

For man to make use of some portion of the electromagnetic environment for communication, radiolocation, radionavigation, or other such purposes, the power of the signal must exceed the power of the noise in that portion of the spectrum at the receiving location. For example, unless the power from WRBN is greater than the atmospheric noise and the man-made noise at 1600 kHz, a person cannot hear that station's programming. Thus, the electromagnetic environment is generally determined by the presence of these signals. Overall, however, the Robins AFB area is a low power density area in comparison with a major metropolitan area.

3.1.1.2 Plants and Animals

Robins AFB has approximately 2,800 forested acres, including roughly 1,000 acres of swamp and wetlands, as well as areas of hardwood (primarily oak) and pine stands. The swamp ecosystem is conducive to hardwood growth, although pine is native to the area and grows rapidly.

The Long-Range Forest Resources Management Plan for Robins AFB for the period 1 October 1981 to 30 September 1991 (USAF, 1981b) provides for the production and harvest of high-quality and high-value timber, as long as those activities are compatible with the military mission, wildlife habitat, watershed protection, and outdoor recreational activities. The proposed PAVE PAWS site is situated in one of five forested areas designated for timber management in the plan. A timber cruise was recently conducted in the PAVE PAWS area by a local contractor who marked selected trees for thinning. During 1983, the Air Force will permit harvesting of timber (i.e., selective thinning) in an area that includes the northeastern portion of the PAVE PAWS project site and clearcutting of a 200-ft circle that would be the radar construction site. One of the other five forested areas designated in the Forest Management Plan is currently categorized as a Unique Natural Area; it is to the north of the proposed radar site near the southern end of the

runway and within the floodplain. According to the Simplified Development Plan, the forested area surrounding the proposed PAVE PAWS site is designated for recreation and the Unique Natural Area is set aside as open space (USAF, 1980c).

The swamp at Robins AFB contains a variety of aquatic plants and is a potential habitat for threatened or endangered plant species. The forested areas and swamp also provide a habitat for a number of large mammals (including deer, feral swine, black bear, and bobcat), small game animals (ranging from rabbit to opossum to fox), and birds (such as hawks, vultures, ospreys, owls, and quail). Horse Creek provides an excellent habitat for waterfowl (USAF, 1976).

The American alligator is the only animal found on base currently listed as threatened or endangered by the Georgia Department of Natural Resources (USAF, 1976). Sightings of the red-cockaded woodpecker, a federally listed endangered species, have been reported at Robins AFB. However, a 1979-1980 survey of red-cockaded woodpecker colony areas in Georgia did not reveal any colonies in either Houston or Twiggs counties (Georgia Department of Natural Resources, Game and Fish Division).

An ecological reconnaissance survey was conducted at Robins AFB during June 1982. The proposed PAVE PAWS project site was investigated for the presence of state or federally listed endangered or threatened plant and animal species. In addition, a vegetation map was prepared (see Figure 3-1).

Within the 60-acre safety zone outside the 10-acre construction site, four habitat types are recognized: pine, mixed pine-hardwood, xeric hardwood, and mesic hardwood. The pine habitat, 35.3% of the vegetated area, is dominated by loblolly pine (*Pinus taeda*), with occasional shortleaf pine (*P. echinata*). Understory species include saplings of red maple (*Acer rubrum*), water oak (*Quercus nigra*), dogwood (*Cornus florida*), and sweet gum (*Liquidambar styraciflua*).

The mixed pine-hardwood habitat, 34.2% of the vegetated area, is codominated by loblolly pine and water oak and understory species similar to those in the pine habitat. Other understory species include smooth sumac (*Rhus glabra*), hawthorn (*Crataegus* sp.), sparkleberry (*Vaccinium arboreum*), and horse sugar (*Symplocos tinctoria*). Ground cover includes Virginia creeper (*Parthenocissus quinquefolia*), Japanese honeysuckle (*Lonicera sempervirens*), and poison ivy (*Rhus racdicans*).

The xeric hardwood canopy is composed of water oak and occasional sweet gum or red maple and covers 25.0% of the vegetated area. Understory species include saplings of the canopy dominants, French mulberry (*Callicarpa americana*), dogwood (*Cornus florida*), sassafras (*Sassafras albidum*), and occasional southern magnolia (*Magnolia grandiflora*).

The mesic hardwood habitat along Sandy Run Creek is composed of several hardwood species and comprises a small portion of the total site, less than 5%. Species present in this habitat include sweet gum,

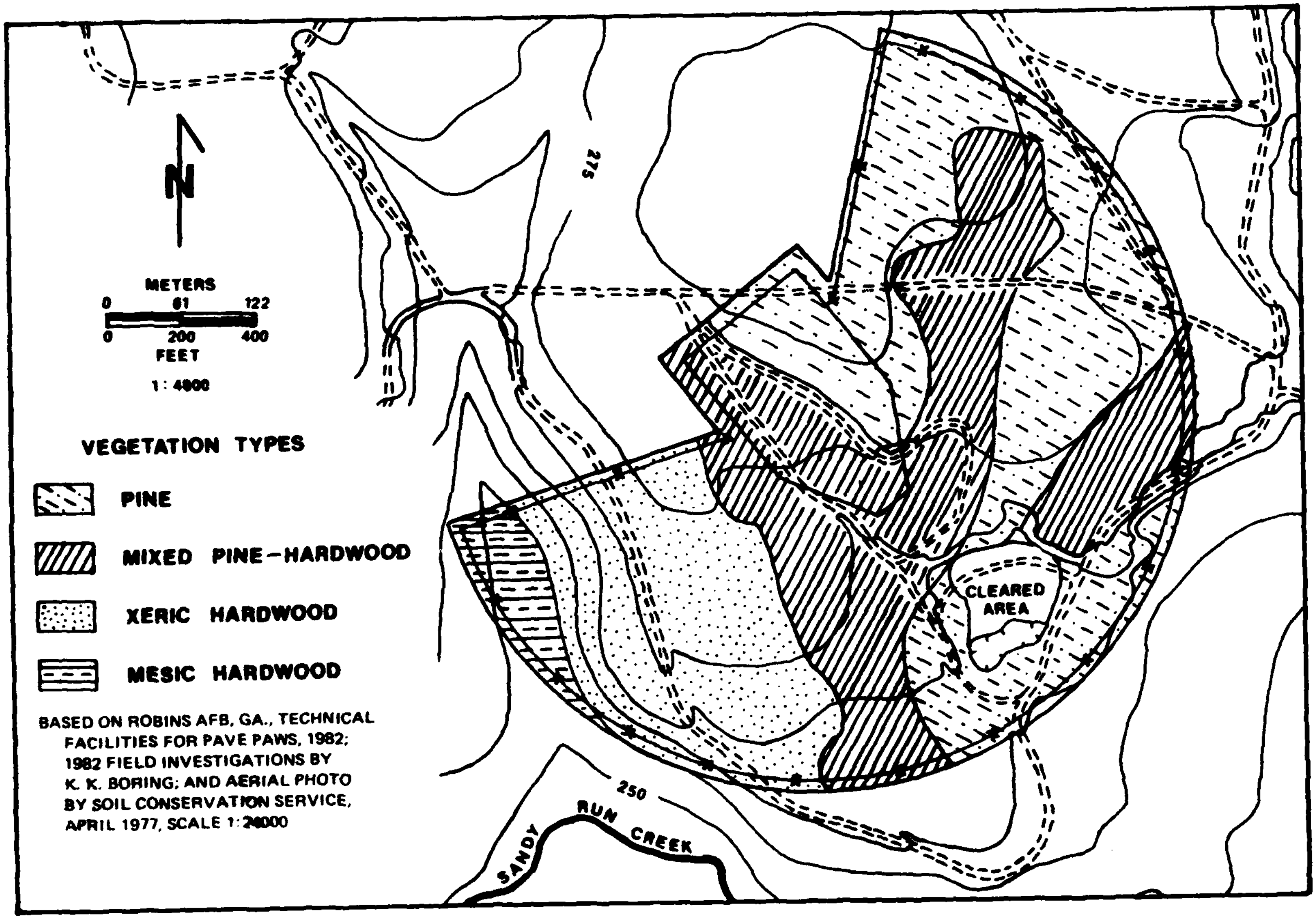


FIGURE 3-1 VEGETATION OF THE PROPOSED PAVE PAWS SITE AT ROBINS AIR FORCE BASE

swamp tupelo (Nyssa sylvatica var. biflora), red maple, cherry bark oak (Quercus falcata var. pagodaefolia), tulip poplar (Liriodendron tulipifera), American beech (Fagus grandifolia), and southern magnolia. The understory is dense with sebastian bush (Sebastiana ligustrina), Virginia willow (Itea virginica), buttonbush (Cephalanthus occidentalis), devil's walking stick (Aralia spinosa), fetterbush (Lyonia lucida), titi (Cyrilla racimiflora), pawpaw (Asimina parviflora), wax myrtle (Myrica cerifera), cane (Arundinaria gigantea), and greenbrier (Smilax sp.).

The 10-acre construction site (Figure 3-1) is vegetated by the pines and pine-hardwoods described above. The site was in agricultural use 20 to 30 years ago. The loblolly pine trees are about 30 years old and are approximately 50 ft (15.25 m) in height and 10-15 in. (25-38 cm) in DBH (diameter breast height). The hardwood species are generally younger and smaller than the pines.

During the 1982 reconnaissance survey, the following birds were heard or seen in the 10-acre construction site and the surrounding 60-acre safety zone:

Broad-winged hawk	Carolina wren
Mourning dove	Gray catbird
Yellow-billed cuckoo	Wood thrush
Barred owl	Blue-gray gnatcatcher
Chimney swift	White-eyed vireo
Pileated woodpecker	Yellow-throated vireo
Red-bellied woodpecker	Red-eyed vireo
Downy woodpecker	Northern parula
Great-crested flycatcher	Pine warbler
Acadian flycatcher	Hooded warbler
Blue jay	Brown-headed cowbird
Fish crow	Summer tanager
Carolina chickadee	Cardinal
Tufted titmouse	Rufous-sided towhee

All of these species are typical breeding birds in the habitats present.

Because a recent (within 5 years), unconfirmed sighting of a red-cockaded woodpecker had been reported on the base, the reconnaissance surveyors placed particular emphasis on determining whether an appropriate habitat for the red-cockaded woodpecker existed on the PAVE PAWS project site. No suitable habitat is present.

Mammals or signs of mammals seen in the project area during the survey include numerous gray squirrels, several cottontail rabbits, raccoon tracks, white-tailed deer tracks, eastern mole runways, and beaver-chewed trees.

3.1.1.3 Air and Noise

3.1.1.3.1 Air. Air quality over the entire Middle Georgia area is classified as pristine (Middle Georgia Area Planning and Development

Commission, 1981a). Robins AFB is in the Central Georgia Instrastate Air Quality Control Region (AQCR). The air quality in that region is in attainment of federal standards. The nearest nonattainment areas are portions of the counties around metropolitan Atlanta, as well as Washington County to the northeast of Robins AFB and Muscogee County on the Georgia-Alabama border. Levels of particulates (in Washington County) and oxidants (in Muscogee County) are higher than federal law permits.

The base has no air quality monitoring stations. According to the Chief of the Bioenvironmental Engineering Services Division on base, Robins and the surrounding area enjoy relatively pollution-free air (Perry, 1982). Data on pollutants sampled from 1975 through 1981 at the monitoring stations nearest the base were obtained from the Georgia Department of Natural Resouces, Air Quality Evaluation Section.

The closest total suspended particulate (TSP) sampling stations are in Bibb County, which borders Houston County to the north and west. At the Macon Airport, located halfway between Macon and Warner Robins, the maximum 24-hr TSP concentrations sampled were 78, 114, 101, and 89 micrograms/m^3 in 1978, 1979, 1980, and 1981 respectively, compared with the Georgia 24-hr standard of 150 micrograms/m^3 (which is also the federal primary 24-hr standard). Measurements taken at several other sampling stations in the Macon area in 1975 through 1979 were in excess of Georgia standards for 24-hr maximum and annual mean concentrations; however, the local trend seems to be toward cleaner air, as TSP concentrations measured throughout all of Bibb County were well below federal and state standards in 1980 and 1981.

Nitrogen oxide and sulfur dioxide levels have also been monitored historically in the Central Georgia Intrastate AQCR. Since 1975, according to data collected at sampling stations in Bibb County, concentrations of these pollutants have been below state and federal standards (Georgia Department of Natural Resources, Air Quality Evaluation Section).

The major sources of emissions on Robins AFB are aircraft (49%), gasoline engines (34%), fuel combustion for commercial/industrial heating (5%), aerospace ground equipment (4%), and surface coatings (4%). In 1981, annual air emissions generated on base were, by weight, carbon monoxide (58%), hydrocarbons (29%), nitrogen oxides (10%), sulfur oxides (1.5%), and particulates (1.5%) (Bioenvironmental Engineering Services Division, 1982). Annual emissions have not increased significantly in the recent past (Perry, 1982).

3.1.1.3.2 Noise. The major source of noise at Robins AFB is air traffic, including production flight tests of F-15, C-130, and C-141 aircraft, as well as takeoffs and landings of B-52, KC-135, and T-series aircraft (see Table 3-1). Noise levels associated with the C-141 aircraft, one of the noisier planes flown out of Robins AFB, are 134 decibels (dBA) at takeoff and 117 dBA during landing. These noise levels

Table 3-1

AIRCRAFT OPERATIONS DURING AVERAGE BUSY DAY: ROBINS AFB

Aircraft Type	Number of Takeoffs and Landings	Percentage
F-4	2	1%
F-15	3	1
B-52G	48	20
C-130B/L-188	32	14
C-141A	23	10
KC-135A	43	18
T-37	47	20
T-38A	24	10
T-39A	5	2
Misc. aircraft	9	4
Total	236	100%

Source: USAF (1982a).

are at or above the human pain threshold (see Table 3-2). For most airplanes, noise levels are assumed to decrease by 6 dBA for every doubling of distance from the source and to be absorbed by the atmosphere at a rate of 1 dBA for every 100 ft (Golden et al., 1979).

According to the Air Installation Compatible Use Zone (AICUZ) Study for Robins AFB (USAF, 1982a), none of the flight tracks is directly over the proposed PAVE PAWS site. The major base runway is about 14,000 ft to the northeast. The primary landing pattern for the major runway is routed approximately 7,000 ft to the northeast of the site, and an approach track is about 4,000 ft to the north.

The results of a study conducted at Robins AFB to evaluate day-night average sound levels (the combination of individual aircraft flyovers and the general noise environment) indicate that the PAVE PAWS site is within a noise contour having a value of 65-70 dBA. Compatible land uses recommended in the AICUZ study for levels in the 65-70 dBA range are commercial/retail trade and business services, recreation, and public and quasipublic services (as long as adequate attenuation is provided).

Motor vehicle traffic and weapons testing are the major sources of nonaircraft noise on Robins AFB. This noise is not audible at the proposed site.

Table 3-2

SOURCES AND LEVELS OF NOISE (dBA)

		dBA	
		190	
			Howitzer
		180	
		170	
	Spontaneous Blast	160	M14 Rifle
		150	
		140	Hand Grenade (75 ft)
Pain Threshold	Jet Takeoff	130	Skil Hammer
	Jet Landing		
	Discotheque	120	Locomotive Whistle
			Chain Saw
		110	Chinook Helicopter
			Bench Grinder
		100	
	New York Subway		Lawnmower
			Air Compressor
	Construction or Noisy City	90	Diesel Truck (25 ft)
			Printing Plant
		80	Alarm Clock
	Freeway		Sewing Machine
Annoyance Level		70	Vacuum Cleaner
	Noisy Urban Residential	60	Conversation
			Window Cleaner
		50	Washing Machine
	Residential		Refrigerator
		40	
	Farm Area		Whisper
		30	Crickets in Wilderness
	Wilderness		
		20	Rustling Leaves
		10	

Source: Golden et al. (1979).

3.1.1.4 Water

3.1.1.4.1 Hydrology. Robins AFB is in the upper Coastal Plain of Georgia where the principal subsurface groundwater supply is the Tuscaloosa Formation, one portion of a larger Cretaceous sand aquifer. Wells ranging from 400 to 600 ft in depth have been developed for both domestic and industrial water supply in the Macon-Warner Robins area. Water levels produced from the wells are measured in terms of millions of gallons per day (mgpd).

In 1962, LeGrand determined that, in the Macon area, "no significant cone of depression has developed in the water table or artesian-pressure surface, not even at Warner Robins or the industrial area south of Macon. In these areas, the natural ground water discharge by evapotranspiration and discharge seepage into streams is great. The potential supply of water from wells in these areas, as well as in almost all other areas of the Coastal Plain, is considerable."

A 1972 study indicated that the expected life of the Tuscaloosa Formation is indefinite and that very little depletion has occurred due to local consumption (Middle Georgia Area Planning and Development Commission, 1972).

Eleven wells with a total capacity of 23 mgpd provide water to the town of Warner Robins. Robins AFB currently has 12 wells, with a total capacity of 14.3 mgpd. Eight of these wells are major wells used as the public drinking water source: one well furnishes water to the Federal Aviation Administration building on base, another is used only to provide drinking water at the skeet range, and two wells are used for water level maintenance at Luna and Scout lakes (Engineering Science, 1982). The latter two wells are located in the recreation area directly to the north of the proposed PAVE PAWS site.

Robins AFB lies within the drainage basin of the Lower Ocmulgee River. Several streams and surface drainage systems originate at or flow through the base property. All of these streams drain in a general west-to-east course and ultimately flow to the Ocmulgee River either via defined creek beds (Horse Creek and Sandy Run Creek) or by dissipated overland drainage through the adjacent swamp areas.

Horse Creek drains out of a small swampy area near the base runway, and Sandy Run Creek forms the southern boundary of the base near the proposed PAVE PAWS site. The Ocmulgee River flows north-south approximately 5,500 ft from the southeast corner of the base.

3.1.1.4.2 Water Quality. In general, the Tuscaloosa Formation is a superb aquifer capable of producing tremendous quantities of water of excellent quality (LeGrand, 1962; Engineering Science, 1982). Drinking water produced from the eight major wells on Robins AFB is adjusted for pH (i.e., lime is added) and treated with fluoride, chlorine, and calgon before being distributed. Throughout the distribution system, periodic sampling is conducted for bacteriological, organic and inorganic

chemical, radiological, and pesticide contamination, in compliance with Environmental Protection Agency (EPA) and Air Force standards. The Bioenvironmental Engineering Services Division on base collects the well water samples and sends them to the Occupational Environmental Health Laboratory at Brooks AFB for analysis. Air Force water quality testing requirements and guidelines are more stringent than those of the state.

Tests of Robins AFB well samples in January 1978 indicated that water quality was excellent, that mineral levels were low, and that levels of the parameters tested were below EPA standards (Engineering Science, 1982). More recent test results for the water distribution system obtained from the Bioenvironmental Engineering Services Division on base show that pesticide levels are less than the qualitative detection limit (i.e., no pesticides were detected) and that levels of other contaminants (including heavy metals) are below the maximum allowable levels specified in the EPA National Interim Primary and Secondary Drinking Water Regulations.

Two surface water quality monitoring stations that are part of the Trend Monitoring Network of the Environmental Protection Division of the Georgia Department of Natural Resources (1980) are located on the Ocmulgee River in the vicinity of Robins AFB--one upstream and one downstream. At both stations, the water is classified for fishing because of the discharge and mixing of large amounts of municipal and industrial wastewater, as well as urban runoff, from the City of Macon. (Fishing is a stream classification indicating water quality determined by the Georgia Environmental Protection Division; other designations are recreation, drinking water, navigation and industrial, and wild and scenic river.)

There are currently eight National Pollutant Discharge Elimination System (NPDES) sampling stations on surface waters within Robins AFB. Water quality is monitored routinely at these stations by the base Bioenvironmental Engineering Services Division and Civil Engineering Squadron in compliance with state and federal requirements. The 1981 NPDES test results at one station indicate that one sample exceeded the 2.0 mg/l ammonia nitrogen limitation with a concentration of 2.4 mg/l. Noticeable oil and grease concentrations were also detected downstream of the industrial wastewater treatment plant. At the other monitoring stations, good water quality values were detected (Engineering Science, 1982).

Two industrial waste treatment plants on Robins AFB can handle 16 million gallons per month of liquid waste generated primarily from aircraft parts manufacturing and aircraft operations. Plant 1 treats wastewater from aircraft washing and engine flushing with chrome reduction, oil and grease removal, and pH control. Some of the chemicals used are ferrous sulfate, sodium hydroxide, sulfuric acid, alum, and polyelectrolyte. Plant No. 2 treats wastewater from plating operations by reducing chrome using sodium bisulfite, by reducing cyanides through chlorination, and by neutralization of acid/alkali wastes. Treated water from Plant

No. 1 is discharged to the base sewage treatment plant (Stewart, 1982; Perry, 1982).

The estimated maximum capacity of the sewage treatment plant on Robins AFB is 2.8 mgpd (Milligan, 1982). Several times during 1981, allowable coliform levels were exceeded, and in January 1982, maximum flow into the facility was 4.2 mgpd (with 1.7 mgpd average flow), somewhat in excess of capacity. In contrast, maximum flow in April 1982 was 2.2 mgpd (1.4 mgpd average flow) (Stewart, 1982). Treatment of wastewater and sewage at the plant includes phenol removal, ammonia stripping, nitrification/clarification, and tertiary filter treatment. Effluent from the facility is discharged into a drainage ditch where it is transported a short distance to Horse Creek (Milligan, 1982). Approximately 30% of the flow of Horse Creek is derived from base discharges (USAF, 1976). Horse Creek, a tributary of the Ocmulgee River, is tested for water quality periodically, particularly when flow is sufficient to allow samples to be collected by boat both upstream and downstream of the sewage treatment plant discharge point.

3.1.1.5 Land and Minerals

3.1.1.5.1 Geology. Georgia is divided into two major physiographic provinces, the Piedmont (north) and the Coastal Plain (south), by a transition zone that runs in a southwest to northeast direction. This Fall Line, a 20-mile zone of sand hills, was once the shoreline of the ocean. Geologically, the Fall Line is the contact between the Cretaceous and younger Neocene sediments of the Coastal Plain and the sediments of the Appalachian Highlands of the Piedmont Province. Stream characteristics change as they flow through this region; rapids and shoals are common as the streams flow out of the mountains into the Fall Line zone. Floodplains and terraces become wider as they approach the younger sediments, and the frequency of stream meanders increases in the Fall Line zone.

Robins AFB is located in the northern portion of the Coastal Plain in what is known as the Fall Line Hills District. In general, this area is highly dissected, with little level land except for the marshy floodplains and their better drained narrow stream terraces. Stream valleys lie 50 to 250 ft below the parallel ridge tops. Dissection is greatest in the eastern portion of the district, and relief gradually diminishes toward the south and east.

The terrain of Robins AFB is a gently rolling series of terraces with marshy lowlands sloping eastward toward the Ocmulgee River. The alluvial surface deposits present on the base are erosion products from the adjacent Piedmont Province. "Unsorted clastics" of fine to coarse sands, clay, and gravel comprise the matrix of formations that are evident. Driller's logs for the 12 water wells on the base provide confirmation that this is the general geologic composition of Robins AFB. The sedimentary formations gathered from the Piedmont by erosion and from the ocean by embayment and deposition total an average thickness of 4,000 ft, the depth to the bedrock underlying the region.

3.1.1.5.2 Soils. The site on Robins AFB selected for PAVE PAWS gently slopes toward Sandy Run Creek to the south and the Ocmulgee River to the east. In 1976, seven soil test borings on a 200-acre parcel were made for a sanitary landfill site that is located along the southeast boundary of the base and includes a portion of the proposed SEPP site. The seven holes ranged in depth from 19 to 25 ft. Log sheets from that project reveal the following:

- Elevations vary from 281 ft in the north to a minimum of 278 ft in the south.
- Site gradients vary from 0% to 2.5%.
- Penetration resistance (blows per foot of advance) ranged as follows: 50, 45, 55, 100, 30, 45, and 70. (These are maximum log points and usually occur near the bottom.) (Soil Systems, Inc., 1976)

Soil profiles taken from the seven test borings were generally erratic. Soils encountered include silty clays of both high and low plasticity, silty sands, clayey sands, and sandy silts. However, clean sands were typically encountered near the groundwater table. The penetration rates encountered in most of the shallow holes indicate a sufficient amount of sandy and clayey strata to provide upward stability under a constant pressure (Soil Systems, Inc., 1976).

Data in the Base Comprehensive Plan indicate that the bearing strength of the soil on Robins AFB ranges between 2,000 and 4,000 pounds per square foot (psf) and that, in some rare cases, it has been as high as 5,000 psf (USAF, 1976).

Groundwater was encountered in each of the 1976 soil test borings. Readings taken 24 hr after the drilling operations show that the depth to groundwater varies from approximately 11 to 21 ft below the ground surface. The soil test borings also indicate that the groundwater position holds at 11 to 21 ft, the adjacent sands are clean, and the groundwater moves generally south to southeast at a rate of 1 ft per month (Soil Systems, Inc., 1976).

3.1.1.5.3 Minerals. Middle Georgia contains several commercially important mineral resources: kaolin, limestone, brick clays, refractory clay, sand, crushed stone, and mica (Middle Georgia Area Planning and Development Commission, 1981a). Kaolin is Georgia's most important industrial mineral; between 40 and 50 principal kaolin mines are in operation in the state. A considerable number of kaolin clay deposits and mines are located along the northern edge of the Coastal Plain and in the Fall Line zone to the northeast of Macon.

According to the Minerals of Georgia (Cook, 1978), Houston County contains two small kaolin pits and a limestone quarry. The kaolin properties continue north from Houston into Twiggs and Wilkinson counties. No other minerals occur in these three counties.

The geologic composition of Robins AFB is sedimentary rock, clay, and sand deposited through erosion from the Piedmont Province as alluvial deposits. Fine to coarse sand is mingled in places with white kaolin. However, these mineral occurrences are thin, stringy, and discontinuous, lacking in bulk (i.e., tonnage), and without economic potential.

In the local area, the 4,000-ft deep cover above bedrock consists of sedimentary formations layered alternately with alluvial deposits from the mountainous Piedmont Province and marine material from seaward embayments. The marine beds have the potential to contain coal, petroleum, or natural gas accumulations, but, to date, no hydrocarbons have been found in the area.

3.1.1.6 Natural Disasters

3.1.1.6.1 Earthquakes. Between 1826 and 1976, 36 earthquakes were recorded in Georgia, two of which were in the vicinity of Robins AFB (Stover et al., 1979). The 1912 quake was centered between Macon and Warner Robins, 9 miles northwest of the base; the 1976 quake, the most recent earthquake reported in Georgia, was located 62 miles southeast of the base. The former was designated moderate (IV on the modified Mercalli scale); the latter was the strongest quake of those documented since 1826 (fairly strong or V on the modified Mercalli scale). The strongest intensity of the scale is XII, signifying a major disaster.

The Structural Geology Map of Georgia shows the nearest fault to Robins AFB as the Goat Rock Fault, situated in southern Monroe County approximately 35 miles to the north of the base. According to the State Geological and Water Survey, there is a considerable "graben" (a dropped or down-thrown block) crossing the general mass of the Coastal Plain somewhat below the Neocene sediments. This feature was caused by deep seated lateral pressure initiated by the spreading of the sea floor. Such movement is, however, generally very gradual and is usually not perceived by man.

3.1.1.6.2 Fire. No fires have occurred near the proposed PAVE PAWS site for more than 25 years, although prescribed burning has taken place on privately owned timberland off base. The Robins AFB Forest Resources Management Plan does call for prescribed burning; however, none has been initiated to date within the base boundary (Ellis, 1982).

3.1.1.6.3 Floods. No serious flooding has occurred on Robins AFB in recent years, although minor flooding has been a problem on the eastern boundary of the base where the water table intersects the surface and forms a swamp. In fact, much of the area bordering the base to the east is low-lying swampland, and parts of the base consist of reclaimed swampland. The local Corps of Engineers has designated intermediate regional and 500-year flood limits around Sandy Run Creek.

3.1.1.6.4 Storms. Severe storms are not common in the vicinity of Robins AFB. In April 1953, however, a tornado swept through the middle

of the base, causing 18 deaths and approximately $10 million in damage. A military housing area was essentially leveled by that storm. In 1975, another tornado touched down about 15 miles west of Robins AFB, causing three deaths and extensive property damage.

Occasionally, thunderstorms are accompanied by squalls, but hurricanes are not considered a potential threat in Middle Georgia. Robins AFB is approximately 200 miles from both the Atlantic Ocean and the Gulf of Mexico.

3.1.2 Socioeconomic Environment

Robins AFB is contiguous with Warner Robins and 10 miles south of Macon, Georgia (see Figure 3-2).

Construction and operation of SEPP at the proposed site will affect the areas with the strongest economic ties with Robins AFB. Table 3-3 shows that 84% of the personnel at Robins AFB live in Houston and Bibb counties. Houston County alone houses 98% of the military and 53% of the civilians who work on base. For this analysis these counties and their primary cities, Macon and Warner Robins, are defined as the region of influence (ROI).

Table 3-3

ROBINS AFB: WORK FORCE BY
COUNTY OF RESIDENCE

County	Military	Civilian	Total	Percent
Houston	3,810	8,163	11,973	63
Bibb	41	3,899	3,940	21
Peach	25	760	785	4
Bleckley	4	464	468	2
Other counties				
6 with 100 or more	8	1,192	1,200	6
15 with 15 to 100	8	718	726	4
25 with less than 15	0	67	67	--
Total	3,896	15,263	19,159	100

Source: USAF (1982b).

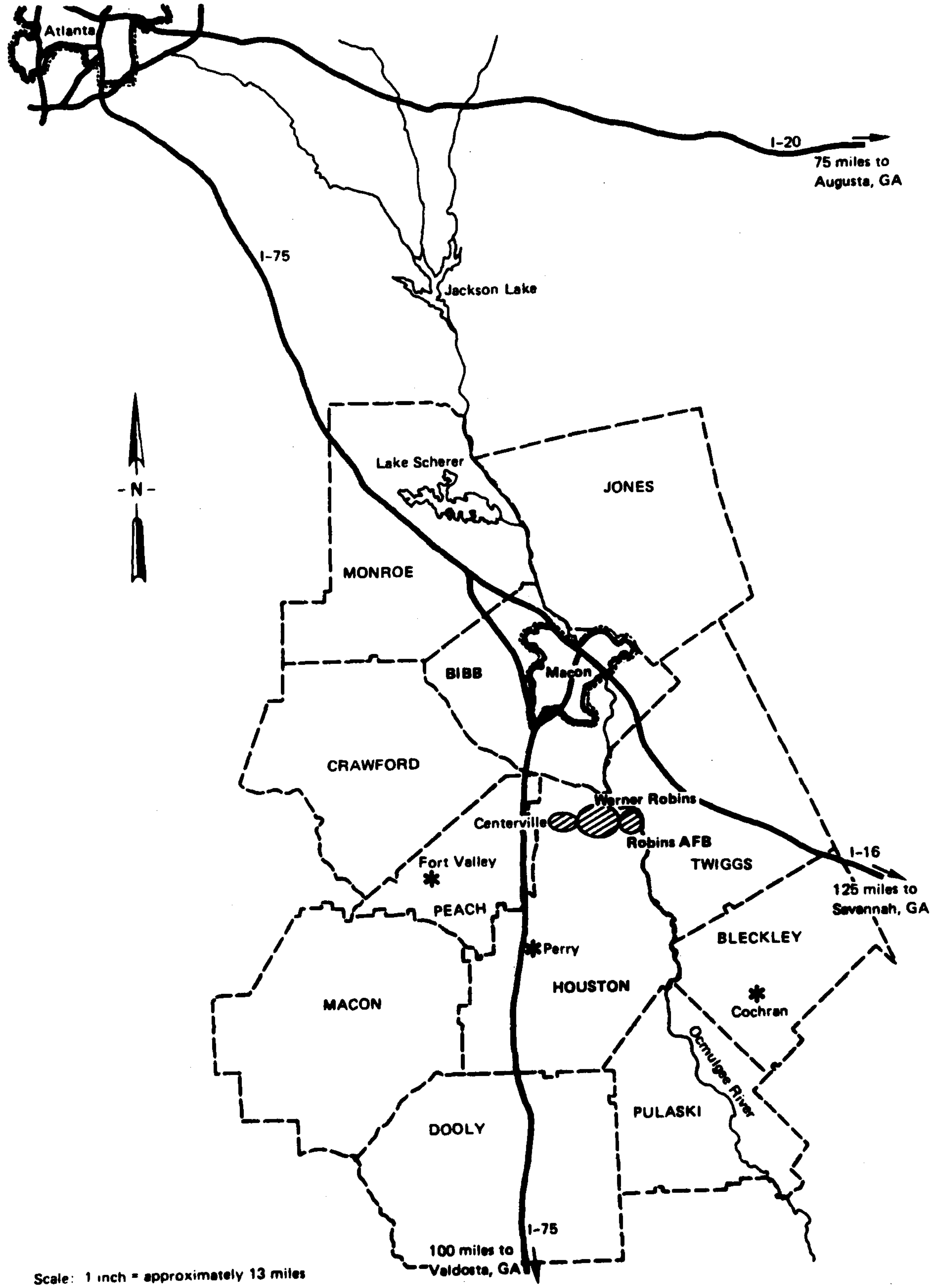


FIGURE 3-2 ROBINS AIR FORCE BASE REGION

3.1.2.1 Employment

The economy of the ROI is diverse, as indicated in Table 3-4, which shows nonagricultural employment by sector for the Macon standard metropolitan statistical area (SMSA). About 90% of the employment in the SMSA, which includes Bibb, Houston, Jones, and Twiggs counties, occurs in the ROI. Between March 1981 and March 1982, the number of both nonmanufacturing and manufacturing jobs in the SMSA increased by 400. Macon is one of six major trade centers in Georgia. Warner Robins, the eighth most populous city in Georgia, is one of three secondary trade centers within the 25-county Macon economic area as defined by the U.S. Department of Commerce, Bureau of Economic Analysis. Between 1967 and 1977, the share of retail sales within the secondary trade centers grew at a greater rate than sales in Macon (Middle Georgia Area Planning and Development Commission, 1981b).

Robins AFB, the largest industrial complex in Georgia, dominates the economy of Houston County. Over the last 25 years, the number of personnel at Robins AFB has remained relatively constant except during the Viet Nam years (see Table 3-5). Between 1976 and 1981 the number of appropriated personnel assigned to the base averaged 19,023, varying by about ±1%. Table 3-6 indicates that an additional 900 personnel are expected between FY 82 and FY 86. The projected number of authorized personnel for FY 86 represents a 4% increase over the 1976-1981 average.

Between 1975 and 1982 the number of jobs in Bibb County decreased by 3,000 (5%), but increased in Houston County by 7,200 (31%), as is evident in Table 3-7. The seven largest manufacturers in Houston County employ a total of 1,525 (Georgia Department of Industry and Trade, 1980). During this period the number of positions at Robins AFB decreased by about 800, an indication that the economy of Houston County is somewhat insensitive to minor losses in employment at Robins AFB.

Between 1976 and 1981 the unemployment rate in Bibb County exceeded the state rate. Since 1978, however, the rate in Houston County has been less than the state rate.

In general, the economy of the ROI is healthy. Employment in Bibb County is less than it was in 1975 but has increased slightly in recent years. Modest growth in the future is probable. The employment outlook in Houston County is stronger. Unemployment is below the state average, and employment continues to grow steadily.

3.1.2.2 Population

The population of the ROI was about 230,000 in 1980 (see Table 3-8). During the 1970s it grew at an average annual rate of 1%, about one-half the state's growth rate during the same period.

Houston County and its primary cities, Warner Robins and Perry, each grew about 2%/yr throughout the 1970s. The growth rate in Bibb County was about 0.5%/yr, although Macon lost about 5% of its population

Table 3-4

MACON SMSA[a]
NONAGRICULTURAL EMPLOYMENT
(Thousands)[b]

Industry	March 1982	Percent	March 1981	Net Change in Jobs
Total nonagricultural employment	98.3[c]		97.5[c]	0.8
Manufacturing	16.8	17	16.4	0.4
Durable goods	5.7	6	5.7	0.0
Lumber and wood products	0.5		0.7	-0.2
Stone, clay, and glass products	1.2		1.3	-0.1
Machinery, except electrical	0.2		0.2	0.0
Other durable goods	3.8		3.4	0.4
Nondurable goods	11.1	11	10.8	0.3
Food and kindred products	2.9		2.6	0.3
Textile mills products	1.3		1.5	-0.2
Apparel and other finished textile products	2.2		2.0	0.2
Paper and allied products	2.3		2.2	0.1
Chemicals and allied products	0.2		0.2	0.0
Other nondurable	2.1		2.3	-0.2
Nonmanufacturing	81.5	83	81.1	-0.4
Contract construction	3.9	4	3.8	0.1
Transportation and public utilities (except U.S. Postal Service)	4.4	4	4.5	-0.1
Wholesale and retail trade	20.0	20	19.8	0.2
Wholesale trade	3.8		3.9	-0.1
Retail trade	16.2		15.8	0.4
Finance, insurance, and real estate	6.3	6	6.1	0.2
Services and mining	17.2	17	17.2	0.0
Government	29.8	30	29.7	0.1
Federal	16.4		16.0	0.4
State and local	13.4		13.7	-0.3

[a]Bibb, Houston, Jones, and Twiggs counties.

[b]This estimate includes all full- and part-time wage and salary workers who were employed during ., received pay for any part of the pay period including the twelfth of the month. Proprietors, domestic servants, self-employed persons, unpaid family workers, and personnel of the Armed Forces are excluded.

[c]Totals may not add due to rounding.

Source: Georgia Department of Labor

Table 3-5

ROBINS AFB: PERSONNEL BY YEAR, 1950 to 1981

	1950	1960	1968[a]	1970	1976 Dec. 31	1977 Dec. 31	1979 Sept. 30	1980 Sept. 30	1981 Sept. 30
Appropriated									
Military	1,700	3,100	6,500	5,400	4,093	4,039	3,959	4,007	3,843
Civilian	7,400	15,700	19,100	17,300	14,755	15,210	14,904	15,042	15,262
Total	9,100	18,800	25,600	22,700	18,848	19,249	18,863	19,049	19,105
Nonappropriated								NA	615
Contract								442	696
Other[b]								105	121
Grand total									20,537

[a]All-time peak level of employment.

[b]Employees of other businesses on base--credit union, bank, post office, etc.

Source: USAF (1978b, 1979c, 1980a, 1981a, 1982c).

Table 3-6

ROBINS AFB: PROJECTION OF AUTHORIZED PERSONNEL, 1981 to 1986[a]

	FY 81	FY 82	FY 83	FY 84	FY 85	FY 86
Military						
Officers	795	810	811	814	816	818
Airmen	3,484	3,527	3,609	3,637	3,681	3,685
Civilian[b]	14,118	14,568	14,430	15,252	15,270	15,276
Total[c]	18,397	18,905	18,850	19,703	19,767	19,779

[a]Projections made in June 1982.

[b]Only authorized personnel are included. In FY 82, 1,432 additional civilian personnel were hired: nonappropriated fund personnel, contract personnel, and employees of other on-base businesses.

[c]The number of authorized personnel does not correspond to the number of assigned personnel (refer to Table 3-5) because of overhiring and underhiring dictated by short-term needs.

Source: Thrasher (1982).

during that period. The greatest decline occurred in the urbanized inner-city neighborhoods. The shift out of the city may be attributed to the growth of suburban industrial parks, the improvement and availability of services in suburban and rural areas, and the greater desire of urban dwellers to reside in suburban and rural environments (Middle Georgia Area Planning and Development Commission, 1981b).

During the 1960s the number of base personnel increased by about 3,900 while the population of Houston County increased by about 23,800. In the 1970s the base lost about 3,600 personnel and the county population increased by 14,700.

Although no formally accepted population projections for the ROI exist, growth during the 1980s is expected to approximate that of the previous decade (Costa, 1982). The anticipated increase of 900 mostly civilian positions at Robins AFB between FY 82 and FY 86 (see Table 3-6) could result in several thousand new residents in the ROI. The extent of the population impact will depend on the number of jobs filled by members of the resident work force.

Table 3-7

ROBINS AFB: ROI CIVILIAN LABOR FORCE, 1975 to 1982

Year	Place	Labor Force (thousands)	Employment Number (thousands)	Unemployment Rate (percent)
1975	Bibb	67.3	62.2	7.5
	Houston	24.8	23.0	7.1
	Georgia			--
1976	Bibb	69.8	62.3	9.3
	Houston	25.6	23.4	8.9
	Georgia			8.1
1977	Bibb	69.6	63.7	8.6
	Houston	25.6	23.5	8.1
	Georgia			6.9
1978	Bibb	60.3	55.7	7.6
	Houston	30.6	28.8	5.6
	Georgia			5.7
1979	Bibb	58.1	54.5	6.2
	Houston	29.6	28.2	4.8
	Georgia			5.2
1980	Bibb	58.6	54.7	6.6
	Houston	29.8	28.3	4.9
	Georgia			6.4
1981	Bibb	63.5	59.2	6.8
	Houston	32.0	30.2	5.7
	Georgia			6.4
June 1982	Bibb	66.1	61.0	7.6
	Houston	32.6	31.2	4.5
	Georgia	2,682.7	2,466.5	8.1

Source: Georgia Department of Labor.

Table 3-8

ROBINS AFB: ROI POPULATION, 1950 TO 1980

	Population				Percent Change	
	1950	1960	1970	1980	1960-1970	1970-1980
Houston County	20,964	39,154	62,924	77,605	60.7	23.3
Warner Robins	7,986	18,633	33,491	39,893	79.7	19.1
Perry	3,849	6,032	7,771	9,452	28.8	21.6
Bibb County	114,100	141,249	143,366	151,085	1.5	5.4
Macon	70,300	69,764	122,371	116,464	75.4[a]	-4.8
ROI	91,300	180,403	206,290	228,690	14.3	10.9
Georgia	3,443,800	3,943,116	4,587,930	5,464,265	14.5	19.1

[a]Much of this growth is attributable to annexations.

Source: U.S. Census Bureau (1981b).

3.1.2.3 Income

The per capita income in the ROI was $7,778 in 1979, or slightly more than the Georgia average and 89% of the U.S. average (see Table 3-9). Between 1974 and 1979 per capita income in the ROI grew 59%, which is comparable to the increase in Georgia and the United States. During that same period total personal income in the ROI increased 61%, or 7% less than in Georgia and the United States.

3.1.2.4 Housing

The amount of housing stock in the ROI grew at a rapid rate during the 1970s (see Table 3-10). Average household size decreased from 3.10 in 1970 to 2.75 in 1980; thus, the number of housing units grew at more than double the rate of population. About 80% of the residences in the ROI are single family homes (see Table 3-11).

Since 1980 the rate of growth of the housing stock in the ROI, as in most regions of the United States, has decreased. High interest rates have adversely affected the ability of buyers to obtain home financing and apartment developers to build economical projects. Between January 1980 and June 1982, 378 housing units were built in Warner Robins; in unincorporated Houston County, permits were issued for 203 single family homes and 440 trailers between June 1980 and June 1982 (Barfield, 1982; Mason, 1982). Representatives of the local real estate industry and

Table 3-9

ROBINS AFB: ROI PER CAPITA INCOME, 1974 AND 1979

	1974 (dollars)	1979 (dollars)	Change (percent)	Percent of U.S.
ROI	4,898	7,778	59	89
Bibb County	4,966	8,157	68	93
Houston County	4,759	7,064	48	81
Macon SMSA[a]	4,273	7,463	58	85
Georgia	4,753	7,627	60	87
Southeast region[b]	4,191	6,251	49	71
United States	5,428	8,757	61	--

[a]Macon SMSA includes Bibb, Houston, Jones, and Twiggs counties.

[b]Southeast region includes Arkansas, Louisiana, Mississippi, Alabama, Tennessee, Georgia, Florida, South Carolina, North Carolina, Virginia, West Virginia, and Kentucky.

Source: U.S. Department of Commerce (1981).

Table 3-10

ROBINS AFB: ROI HOUSING STOCK, 1970 AND 1980

	Housing Units[a]			Population Change, 1970-1980 (percent)
	1970	1980	Change (percent)	
Houston County	19,106	27,423	43.5	23.3
Warner Robins	10,662	14,777	38.6	19.1
Bibb County	47,397	55,821	17.8	5.4
Macon	41,107	44,276	7.7	-4.8
ROI	66,503	83,244	25.2	10.9

[a]Includes vacant and occupied housing units.

Source: U.S. Census Bureau (1981b).

Table 3-11

ROBINS AFB: ROI HOUSING UNITS AT SINGLE ADDRESS
(Number of Units)

	1	2-9	10+	Mobile Home	Total
Houston County	22,057	1,602	1,370	2,361	27,390
Warner Robins	12,343	776	1,082	572	14,773
Bibb County	44,232	6,946	3,088	1,295	55,561
Macon	34,556	6,556	2,922	239	44,273
ROI (total)	66,289	8,548	4,458	3,656	82,951
ROI (percent)	79.9	10.3	5.4	4.4	100.0

Source: U.S. Census Bureau (1982).

governmental agencies believe that pent-up demand for housing is strong and that many developers will start projects when interest rates decrease to an acceptable level (Greer, 1982; Barfield, 1982; Mason, 1982).

The vacancy rates in 1980 are enumerated in Table 3-12. Although more recent figures are unavailable, the vacancy rate for rentals is now probably lower than the 1980 level and the rate for owner-occupied homes is higher. Because of the high interest rates and lack of building in recent years, people who might normally buy housing seek rentals. In July 1982 about 350 homes were listed for sale on the multiple listings in Warner Robins, including all areas within 5 miles of the city (Greer, 1982). The rental market is described as tight, likely to have less than 5% vacancies, but not critical (Greer, 1982). Representatives of the Robins AFB housing referral office state that a shortage of apartments and mobile homes for rent exists but that military personnel are finding places to rent (Smith, 1982).

In 1980 the median value of homes was $37,300 in Houston County and $32,300 in Bibb County (U.S. Census Bureau, 1982). There has been little appreciation in value since that time (Greer, 1982). A typical 2-bedroom, 1-bath apartment rents for about $175 to $275, and a 3-bedroom, 2-bath townhouse rents for less than $400. As was shown in Table 3-11, most apartment houses are small (less than 10 units); they are not managed by real estate professionals. Rents tend to lag behind market rates but are likely to appreciate with the continuation of the presently tight market conditions.

Table 3-12

ROBINS AFB: ROI HOUSING STOCK AND VACANCY RATES, 1980

	Owner Occupied			Rental		
	Occupied	Vacant, For Sale	Vacancy Rate (percent)	Occupied	Vacant, For Rent	Vacancy Rate (percent)
Houston County	13,211	333	2.3	6,958	727	9.5
Warner Robins	7,978	205	2.5	4,344	446	9.3
Bibb County	37,415	1,800	4.6	19,624	1,563	7.4
Macon	19,860	303	1.5	18,216	1,392	7.1
ROI (total)	51,626	2,133	4.0	26,582	2,290	7.9

Source: U.S. Census Bureau (1982).

On-base housing resources for permanently assigned military personnel consist of 1,396 family housing units, 100 mobile home spaces, and 1,106 dorm beds. On May 26, 1982, the waiting list for family housing consisted of 34 officers (1- to 2-month wait), 114 eligible enlisted men (1- to 4-month wait), and 145 ineligible enlisted men (up to 24-month wait).* In July 1982 the housing stock was at its practical capacity. At that time 2,570 military personnel lived on base and 1,330 lived off base. Many senior personnel (typically E-8s and 9s and senior officers) seek housing off base.

In recent years lower grade enlisted men (E-1 to E-4) have experienced difficulty in obtaining adequate housing off base. Their salaries have not kept pace with rents; in January 1981, for example, the families of 44 enlisted personnel (2% of enlisted personnel strength) lived in substandard quarters (Thornal, 1981). This situation could worsen because the City of Warner Robins has an active program to remove substandard housing. However, representatives of the community, city,

*Personnel in grades E-1 to E-3 and E-4s with less than 2 years of service are not eligible for on-base housing until the waiting list for all other (i.e., eligible) enlisted personnel is exhausted.

and base are presently seeking ways to provide low-cost housing in the neighborhood where much of the substandard housing is located (Matragano, 1982; Greer, 1982).

Transient housing stock in the ROI is extensive. The five motels in Warner Robins have a combined total of 497 rooms. Perry, a city of about 9,000 located on Interstate 75 about 10 miles southeast of Warner Robins, has 18 motels and 1 hotel with 1,002 rooms. The average annual occupancy rate is about 65%.

3.1.2.5 Education System

The 24 schools in the Houston County School District provide education for the school-age children of all county residents. Total enrollment at the beginning of the 1981-82 school year numbered 15,032 students. Of this total, 1,409 (9%) were children of AF personnel. Table 3-13 presents the total enrollment and number of AF-related students for schools in the district.

Over the past 3 years, school district enrollment has declined at an average annual rate of 1.7%, resulting in a total enrollment reduction of 800 students. Enrollment is expected to continue to decline over the next 2 years, with losses of 200 and 150 students anticipated for the 1982-83 and 1983-84 school years, respectively. Thereafter, total school district enrollment is expected to stabilize at approximately 14,700 students. Southside Elementary in Perry was closed during

Table 3-13

HOUSTON COUNTY SCHOOL DISTRICT ENROLLMENT, 1981-1982

Schools	Total Enrollment	Children of AF Personnel
Warner Robins schools	10,764	1,227
Perry schools	2,852	25
Other community schools		
Bonaire Elementary (K-6)	756	121
Centerville Elementary (K-6)	660	36
Subtotal	1,416	157
Total	15,032	1,409

Source: Andrews (1982).

the last school year, and closure of Elberta Elementary in Warner Robins is being considered. School district officials hope, however, that the new housing being constructed near Elberta Elementary will provide enough students to keep the school open.

3.1.2.6 Community Facilities and Services

In general, the municipalities within Houston County are responsible for providing public services and facilities to people living within the city limits. The county is responsible for serving the needs of county residents within unincorporated areas. The cities commonly have mutual aid agreements with the county and with Robins AFB to provide assistance when requested for fire fighting and the like. There are no significant facility and service deficiencies.

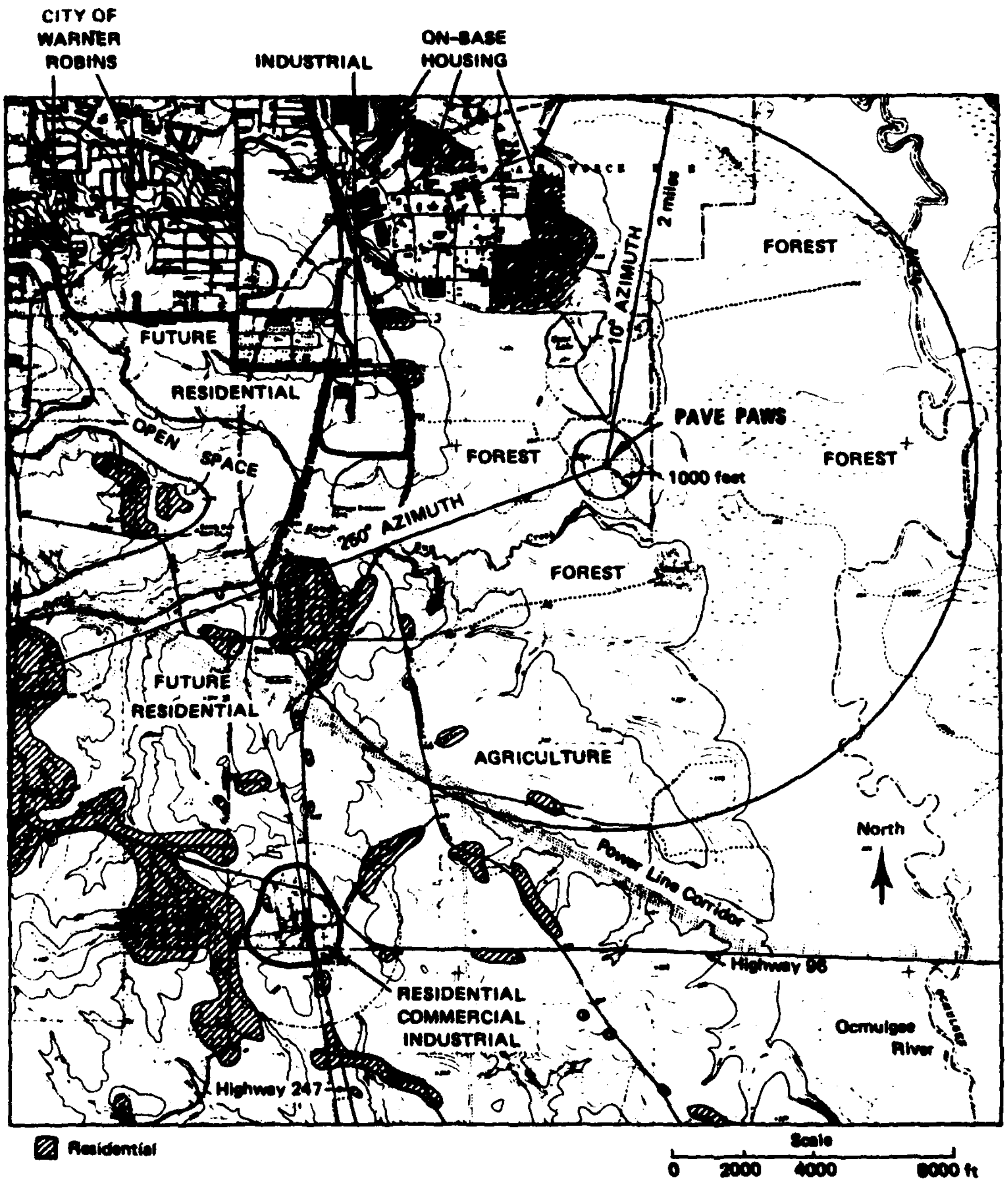
3.1.2.7 Land Use

The proposed site of SEPP is in the southeast corner of Robins AFB. The scan of the radar will be over lands to the northeast, southeast, and southwest of the site (see Figure 3-3), most of which are unincorporated portions of Houston County. To the rear of the radar (the northwest quadrant) are Warner Robins and Robins AFB, which are situated in an unincorporated area of Houston County. Both Warner Robins and Houston County have zoning ordinances.

Land uses at Robins AFB are as diverse as those in any municipality. Uses include residential, commercial, outdoor and indoor recreational, circulation (road, rail, and airport), and various industrial land use categories. A nature center is located about 1 mile north of the SEPP site, and parts of the related trail system cross the proposed site.

The land in the eastern portion of the base and between the base and the Ocmulgee River is swamp and dense forest. This land and the land immediately south of the base is owned by three forest product companies. The area to the south, bounded by Highway 247 in the west, the transmission line corridor to the south, and the Ocmulgee River to the east, also contains extensive stands of timber; however, much of it has been cleared for farming. Most (1,800 acres) of this area is in single ownership (Houston County Assessor, 1982).

A few residences are located within this farming area and scattered along Highways 247 and 96. The land to the west of Highway 247 is used more intensely. The small settlements of Bonaire and Lashley are located at the intersection of Highways 247 and 96. North of Bonaire, along the west side of Highway 247, are agricultural areas and scattered residences. Immediately southwest of the base is a small suburban subdivision and mobile home park containing about 100 residences. West of the base and the proposed site is an industrial tract within the Warner Robins city limits. The balance of the city lies to the north.



SOURCE: Houston County Assessor (1979)

FIGURE 3-3 ROBINS AFB VICINITY LAND USE

The land uses on and around the base are not expected to change significantly in the foreseeable future (Middle Georgia Area Planning and Development Commission, 1980). Warner Robins is expanding to the south. At present, a few isolated subdivisions are located between the corporate limits of Warner Robins and Highway 96. Low density residential growth is expected to continue in this area. Industrial growth is also likely to continue within the areas along Highway 247 presently zoned for industry.

The timber and agricultural uses south and east of the installation are expected to be maintained. Residential growth along the east side of Highway 247 is possible.

3.1.2.8 Aesthetics

The proposed site of PAVE PAWS is densely foliated with 50- to 75-ft pine trees. The site is part of a homogeneous forest that comprises the Ocmulgee River basin and occupies areas on and to the east and south of Robins AFB. Because of the relatively flat terrain and the dense forest that surrounds the site, PAVE PAWS is not directly visible except from within the forest.

3.1.2.9 Cultural Resources

A cultural resource survey of the PAVE PAWS site was conducted in June 1982 to determine the presence or absence of cultural resources that might be affected by the proposed construction. Prior to the survey, a search of the Georgia Archeological Site Files at the University of Georgia was initiated. The search revealed that two previously discovered archeological sites were in the general vicinity of the proposed PAVE PAWS facility. In 1977, archeologists examining a proposed sewer line corridor along Sandy Run Creek from Warner Robins Wastewater Treatment Facility #2 to the Ocmulgee River discovered sites 9Ht7 (Warner Robins 1) and 9Ht8 (Warner Robins 2) (Griffin and Miller, 1977). They reported finding aboriginal pottery, a stone bowl fragment, stone tools, and debitage. (Debitage are small flakes or chips produced during the process of shaping rocks into tools.) Site 9Ht7 yielded 12 pieces of chert debitage from about a 300-ft section of dirt road. Site 9Ht8 was larger (600 ft along a dirt road) and yielded 93 artifacts dating to the Late Archaic (3,000-1,000 B.C.) and Early Woodland (1,000 B.C.-A.D. 500) periods. Although the archeologists did not perform shovel tests, they declared both of the sites superficial and lacking in contextual integrity.

Other prehistoric archeological sites are located on high terraces along the floodplain of the Ocmulgee River and its tributaries. Judging from the site files search, the area was occupied rather extensively during most of the Holocene. No historic sites or structures were recorded from the project site.

The June 1982 cultural resource survey was concentrated in two areas of the proposed project where construction activities are likely--the area of the proposed PAVE PAWS facility (10 acres) and the perimeter road and fence that encircles the 60-acre safety zone. The survey techniques were designed to thoroughly examine all exposed ground surfaces and to excavate shovel tests periodically in areas where thick vegetation masked the ground's surface. When artifacts were discovered on the surface, a series of shovel tests was excavated in the immediate area.

Site 9Ht8 was relocated and reevaluated by taking a surface collection of artifacts from the dirt road bed and excavating 14 shovel tests in two transects across the site. It was determined that site 9Ht8 straddled the PAVE PAWS perimeter (1,000-ft) fence and road as proposed in the initial site plan (see Figure 3-4). Other areas of the PAVE PAWS site were also carefully examined. The soil from all shovel tests was screened through 0.5 in. mesh to recover artifacts.

The results of the cultural resources survey suggest that site 9Ht8 may not be a superficial artifact scatter lacking integrity, as previously reported (Griffin and Miller, 1977). The size of site 9Ht8 was also found to be substantially larger than previously reported. Information from the surface collection and shovel tests indicates that it is about 1,310 ft long (E-W) by 260 ft wide (N-S). In the shovel tests, the artifacts most commonly occurred at 10 to 15 in. below surface and often extended to 2 ft below surface. Seldom were artifacts encountered above 1 ft. The artifacts collected from the shovel tests and surface reveal that the site was occupied during the Early Archaic (8,000-6,000 B.C.) and Late Woodland (A.D. 600-A.D. 900) periods. Table 3-14 presents the most recent artifact inventory from the site.

Table 3-14

ARTIFACTS FROM SITE 9Ht8

	Aboriginal Pottery		Chert		
Origin	Stamped	Plain	Tools	Debitage	Total
Surface	1	1	2	45	49
East transect (5 shovel tests)	2 (LW)	1	3 (1 EA)	26	32
West transect (4 shovel tests)	1	0	2 (1 EA)	6	9
Total	4	2	7	77	90

Note: LW = Late Woodland; EA = Early Archaic.

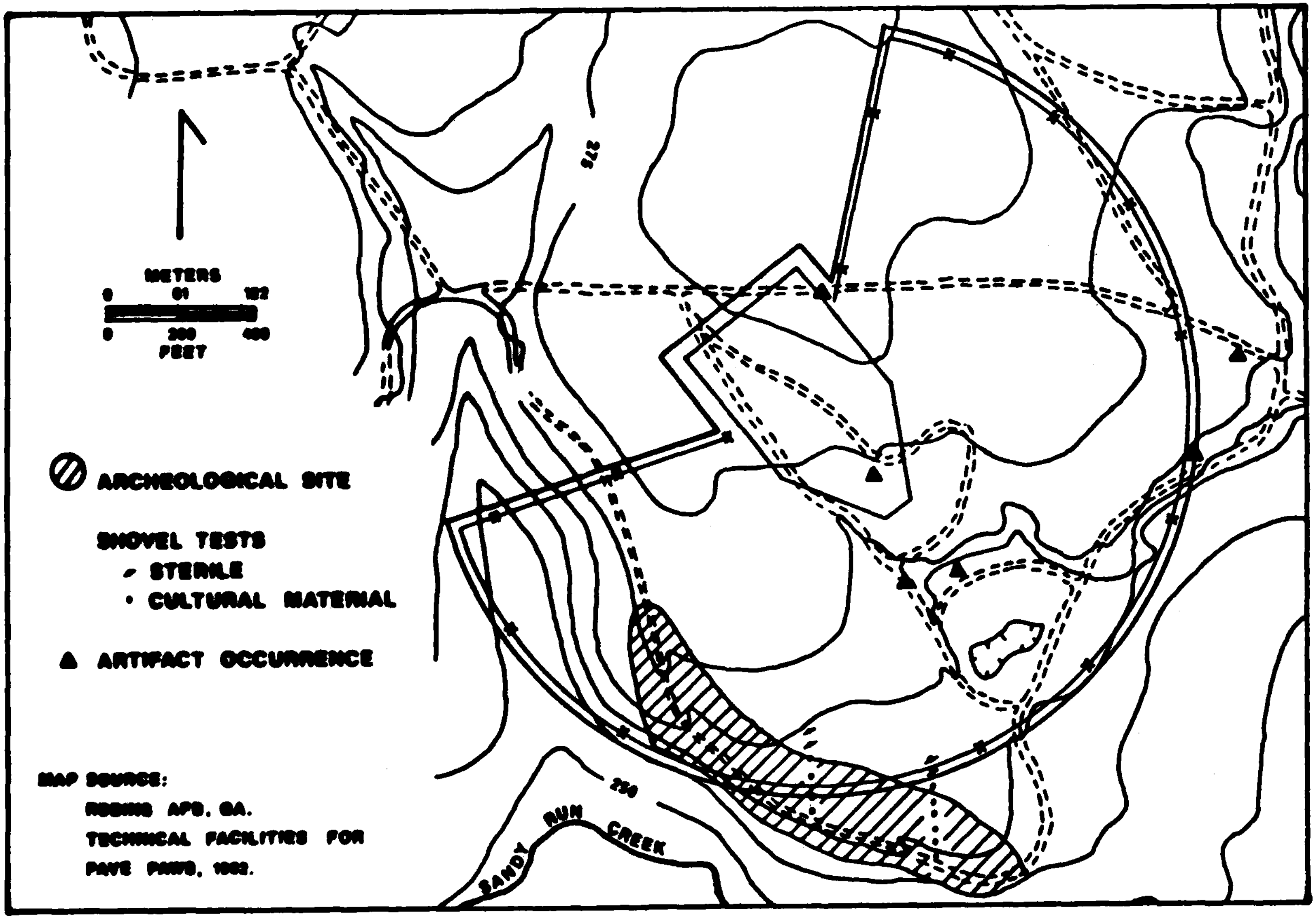


FIGURE 3-4 ARCHEOLOGICAL SITE 9Ht8 AND ARTIFACT OCCURRENCES NEAR PAVE PAWS

The surface collection from the dirt road may not be representative of the site because this area most likely has been subjected to frequent collecting by archeologists and local artifact collectors in the past. Diagnostic artifacts (decorated sherds and projectile points) probably have been removed. The material from the shovel test transects is probably more representative of the site's assemblage. The east transect (Figure 3-4) yielded a higher density of artifacts and more diagnostics than the west transect. Shovel tests on the east transect averaged five pieces of chert debitage per test--a moderately high density.

To further delineate the boundary of site 9Ht8, additional testing (i.e., posthole digging) was conducted in October 1982. This check demonstrated that the site is buried beneath 12 to 20 in. of yellowish sand. Large percussion flakes and two chipped stone tools were recovered. Two more projectile points, two sherds of simple stamped pottery and numerous chert flakes were uncovered during a surface reconnaissance of the graded road bed.

The eligibility of site 9Ht8 for the National Register of Historic Places is uncertain at this time. While it is known that the site was occupied from Early Archaic to at least Late Woodland times and it is suspected that relatively dense deposits are sealed, it is not known whether the deposits are stratified or homogenized by bioturbation (e.g., tree roots, animal burrows). The techniques of shovel testing and posthole digging are not sensitive enough to determine whether the site is stratified or contains important cultural features. Formal test excavations and evaluation would be necessary to determine whether or not the site meets the criteria for nomination to the National Register of Historic Places.

The cultural resources survey also discovered artifacts north of and uphill from site 9Ht8. Examination of all dirt roads and clearings inside the 60-acre safety zone uncovered five artifact occurrences (Figure 3-4). Extensive shovel testing near these occurrences revealed no additional material--no stains on the soil from organic residue (midden) were observed. The occurrences consisted of one to four pieces of debitage scattered over broad areas.

The occurrences are not considered to be archeological sites, although they do indicate sporadic use of the area by prehistoric people. Artifact occurrences such as these are probably very common along the terraces overlooking the vast Ocmulgee River flood plain. Such artifact occurrences are not eligible for the National Register of Historic Places because they will not contribute new information about the aboriginal occupation of the area.

Site 9Ht7 was relocated but found to be entirely outside the 60-acre safety zone. No collections were made and the site was not tested.

3.2 Moody AFB (Alternate Site)

3.2.1 Biophysical Environment

3.2.1.1 Electromagnetic Environment

The electromagnetic environment (prior to the introduction of a PAVE PAWS radar) described for Robins AFB in Section 3.1.1.1 is sufficiently general that it applies as well to the vicinity of Moody AFB. Although specific local emitters of electromagnetic energy were named, similar or equivalent emitters are located in the Moody AFB area.

3.2.1.2 Plants and Animals

Moody AFB has approximately 1,400 acres of forest land, 1,100 acres of semi-improved grounds surrounding the airfield, and 2,100 acres of unimproved grounds. The latter acreage includes three lakes: Grassy Pond (261 acres; used for recreation), Lots Pond (67 acres), and Mission Pond (37 acres).

In addition to the Grassy Pond Recreational Area, which is actually outside the main base and encompasses trees as old as 150 years, there are a number of specially designated habitats on the perimeter of Moody AFB. Banks Lake, a cypress lake to the north of the base, is owned and managed by the Nature Conservancy, a private organization that purchases and maintains areas with specific ecological value. Dudley's Hammock Natural Area is located between the base and the proposed PAVE PAWS site. Grand Bay Public Hunting Area, encompassing the proposed PAVE PAWS site, is a game management area jointly maintained by the Georgia Game and Fish Commission and the U.S. Forest Service.

An inventory has not been conducted of the plants and animals on the base as a whole. According to TAB A-1, Environmental Narrative for Moody AFB (USAF, 1978a), the American alligator is known to inhabit the base, and the following are endangered or threatened animals known to be within a 50-mile radius of the base: southern bald eagle, red-cockaded woodpecker, Florida sandhill crane, and Florida panther. The 1979-1980 survey of the red-cockaded woodpecker in Georgia (Georgia Department of Natural Resources, Game and Fish Division) indicates that the nearest colonies are to the west in Thomas County (on private quail plantations) and to the east in Cinch and Ware counties and the Okefenokee National Wildlife Refuge and Wilderness Area in Charlton County.

An ecological reconnaissance survey of the PAVE PAWS site was conducted during June 1982. The site was inventoried for the presence of state or federally listed endangered or threatened plant and animal species. The proposed 60-acre safety zone outside the construction area of the PAVE PAWS project at Moody AFB is mostly situated on a former paved runway, as positioned in Figure 3-5. The runway was used in the 1940s for landing and takeoff and has been abandoned since 1951 except for fuel jettison and bail out. Portions of the area are presently covered by crumbling pavement. Grasses and forbs present include

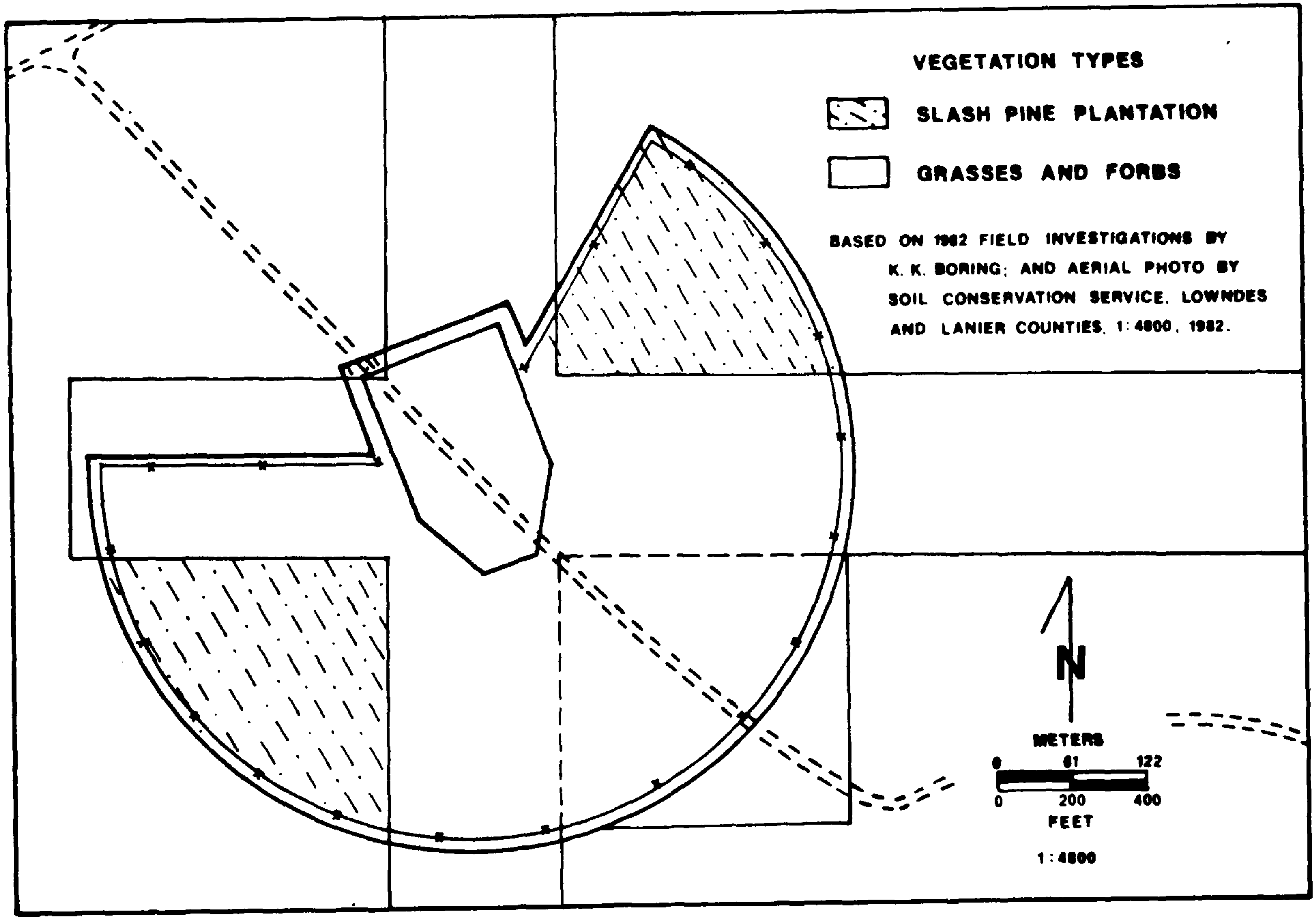


FIGURE 3-5 VEGETATION OF THE PROPOSED PAVE PAWS SITE AT MOODY AIR FORCE BASE

broomstraw (Andropogon sp.), carpet grass (Axonopus affinus), crabgrass (Digitaria sanguinalis), centipede grass (Eremochloa ophiurioides), Saint John's Wort (Hypericum sp.), and dog fennel (Eupatorium capillifolium). Other species in abundance include yellow meadow beauty (Rhexia lutea), common meadow beauty (R. virginica), and rattlesnake master (Eryngium yuccafolium). This open area is mowed semi-annually. Also within the 60-acre safety zone are planted slash pines (Pinus elliottii), approximately 10 to 15 years old and 20-30 ft (6-9 m) tall. Occurring among the planted pines are blackberries (Rubus sp.), fetter-bush (Lyonia lucida), sweet bay (Magnolia virginiana), wax myrtle (Myrica cerifera), Virginia willow (Itea virginica), groundsel tree (Baccharis halimifolia), poison oak (Rhus toxicodendron), squaw-huckleberry (Vaccinium stamineum), saw palmetto (Sereno repens), and young water oak (Quercus nigra).

The 10-acre site to be affected by construction of the PAVE PAWS facility falls within the old runway described above. No wildlife or wildlife signs were seen within the project boundary; however, white-tailed deer, cottontail rabbit, possum, and raccoon, which are abundant in surrounding forest habitats, are apt to occasionally use the open area. No habitat at the site is suitable for redcockaded woodpeckers.

3.2.1.3 Air and Noise

3.2.1.3.1 Air. Moody AFB is in the Southwest Georgia Intrastate AQCR where air quality is in attainment of federal standards. Fifty miles east of Valdosta, the Okefenokee Wilderness Area is a mandatory Class I Prevention of Significant Deterioration (PSD) Area, where allowable new degradation of air quality is severely limited.

No air quality monitoring stations are located on Moody AFB. There is a monitoring station, however, in Valdosta at the Lowndes County Health Department. TSP and sulfur dioxide samples collected there between 1975 and 1981 never exceeded state or federal standards. At another sulfur dioxide monitoring station in Dougherty County to the northwest of Moody AFB, levels of that pollutant have also been below standards since 1975 (Georgia Department of Natural Resources, Air Quality Evaluation Section).

In 1980, an air pollution emission inventory was conducted for Moody AFB (Environmental Health Services, 1981a). Different sources on base contributing to total emissions that year were aircraft (55.6%); road vehicles, including aerospace ground vehicles (37.4%); evaporation due to fuel storage and transportation and surface coating (painting) activities (4.8%); industrial fuel combustion (1.4%); fire training activities (0.4%); and fuel spills (0.4%). The 1980 percentages for pollutant type by weight were: carbon monoxide (65.3%), hydrocarbons (16.7%), nitrogen oxides (13.4%), sulfur oxides (2.1%), and particulates (2.5%).

3.2.1.3.2 Noise. The major sources of noise are the approximately 70 F-4 Phantoms and the other aircraft based at Moody. The average daily number of operations by principal aircraft are shown in Table 3-15.

Table 3-15

AIRCRAFT OPERATIONS DURING AVERAGE BUSY DAY: MOODY AFB

Aircraft Type	Number of Takeoffs/Landings	Low Approaches
F-4E	105	85
F-4D	4	1
T-37	2	1
T-38	2	1
Other	1	-
Total	114	88

The two base runways are located approximately 13,00C ft to the northwest of the proposed PAVE PAWS site. The flight tracks for take-offs and landings are not directly overhead but encircle the site to the south and east at a distance of about 6,000 ft. The site is outside the noise contours associated with Moody aircraft (i.e., the day-night average sound level is less than 65 dBA).

Vehicle traffic and weapons testing are additional sources of noise on Moody AFB, but these noises cannot be heard at the abandoned landing strip proposed for the radar installation.

3.2.1.4 Water

3.2.1.4.1 Hydrology. Potable groundwater is obtained at Moody by drilling into a subsurface artesian aquifer, known as the Hawthorne Formation, that is recharged by rainwater percolation. The depth of the aquifer ranges from 100 to 1,600 ft and the yield from 50 to 6,000 gpm (Georgia Chamber of Commerce). The local water level appears to have fallen about 4 ft in the last 10 years, although the expected lifetime of this limestone aquifer is indefinite. Groundwater moves in an easterly direction toward the Atlantic (USAF, 1978a).

Driller's logs and drawdown tests of the three wells on base near the former runway proposed as an alternate PAVE PAWS site indicate strata of soft to hard rock in varying thicknesses. Layers of sand, clay, blue marl, limestone, kaolin, and Fuller's earth were identified in the wells. Thus, a number of sands contribute to the groundwater supply at Moody AFB. Pertinent data on the three wells are as follows:

Well No.	Depth (ft)	Top of Water (ft)	Drawdown Test
913	425	Not given	24-hr test produced 500 gpm (10-in. casing)
946	425	144	24-hr test produced 500-520 gpm (12-in. casing)
1,112	250	108	15-hr test produced 180 gpm

Well No. 1,112, also called Ordnance Well, is east of the main airstrip area on Moody and closest to the PAVE PAWS site (approximately 2 miles away). The performance and supply of a new well at the site are likely to be similar to this existing well (Eiseman, 1982).

Moody AFB is located in the Suwannee River Basin. Surface runoff waters on base flow into Beatty Branch Creek (an intermediate tributary) and Cat Creek and Grand Bay Creek (two tributaries with a steadier flow) on their way to the Alapaha and Withlacoochee Rivers. The Alapaha flows north-south on the east side of the base, and the Withlacoochee in the same direction on the west side of the base. The latter waterway drains, in turn, into Florida's Suwannee River.

3.2.1.4.2 Water Quality. Eleven wells supply potable water on Moody AFB; the three that are considered the main base wells have a capacity of 2.5 mgpd. During April 1982, daily average water production on base was 558,000 gal. The well water is aerated, chlorinated, and fluoridated before it is distributed throughout the base.

Periodic chemical, bacteriological, radiological, metal, and sulfur analyses are conducted on well output and on water in the distribution system. Data for 1976 and 1977 indicate that the water supply in those years was in compliance with EPA National Primary and Secondary Drinking Water Regulations.

The two closest Trend Monitoring Network water quality sampling stations are located southwest of the base and north of Valdosta on the Withlacoochee River. The U.S. Geological Survey conducts routine chemical analysis on samples. The Withlacoochee receives a number of treated discharges from small cities and industries as well as a large municipal and a large industrial treated discharge from Tifton, 50 miles upstream of Valdosta. The river is classified for fishing (Georgia Department of Natural Resources, Environmental Protection Division, 1980).

Moody has a sewage treatment plant with a capacity of 750,000 gpd located to the west of the main base across Georgia Highway 125. The recently modernized plant incorporates the following processes: primary and secondary treatment, sludge digestion, sludge drying beds, and chlorination of plant effluent prior to final discharge. Sewage plant

influent and effluent are periodically sampled. During the summer months of 1976, 1978, and 1980, levels of ammonia nitrogen in the sewage plant effluent were in excess of NPDES standards (Environmental Health Services, 1981b). Plant effluent is discharged into Beatty Branch Creek from which samples are collected weekly and tested for biochemical oxygen demand and dissolved oxygen. Downstream uses of the creek include agriculture, livestock water, and irrigation.

The POL (petroleum oil lubrication) and flight line storm drains, which discharge into Mission Pond, are also sampled periodically. Oil separators and grease traps are employed before water is discharged to the storm drain or sanitary sewage system. The oil separators are designed to collect accidental spills (Environmental Health Services, 1981b). The storm drainage system for the rest of the base empties into Grand Bay Creek and Beatty Branch Creek.

3.2.1.5 Land and Minerals

3.2.1.5.1 Geology. Moody AFB, occupying portions of Lanier and Lowndes counties, lies in the Tifton Upland District. This district is a subregion of the lower Coastal Plain Province and contains undifferentiated sedimentaries classified as Neogene, or post-Cretaceous in age. The surface geology is dissected by a well-developed dendritic drainage pattern (i.e., similar to the pattern formed by a tree and its branches) sloping toward the southeast margin made by the drainage divide of the Alapaha River. Stream valleys in the region accept and contribute recharge surface water to maintain artesian aquifers.

In general, the region has alluvial rolling terrain. Karst (uneven or abrupt) topography dominates the landscape of south central Lowndes County. A soil survey of Lowndes County mentions limestone sinkholes as a typical feature of the Tifton Upland District (Stevens, 1979). Topographic maps covering both Moody AFB proper and the proposed PAVE PAWS site off base show very few limestone sinkholes, although the bogs and marshes evident along the river course may result from underlying limestone solution caves. Grand Bay Swamp is a lime sink containing an extensive accumulation of peat. Limestone sinkholes in some southeastern states have collapsed underneath roads and highways and have caused significant damage. The possibility of sinkhole collapse at Moody was discussed with the base's Corps of Engineers staff who indicated that there is no history of recent sinkholes on or in the immediate vicinity of the base.

3.2.1.5.2 Soil. Soil cover surrounding the former runway east of Moody AFB contains a varying mixture of sand, loamy sand, sandy loam, and sandy clay loam to depths of 65 in. Soil types include Leefield, Marcotte, Pelham, and Tifton. The latter has been categorized as having good potential for openland (e.g., grasses and herbaceous plants) and woodland (e.g., hardwood and conifer) plants and associated wildlife, but poor potential for wetland plants and wildlife (Stevens, 1979). The soils can also be categorized as imperfectly or poorly drained. A predominant quantity of fines makes these sands of little use for

construction purposes; very little gravel was found in the upper strata of the driller's logs from the main wells on the base.

The bearing strength of subsurface soils in the western portion of the base ranges from 3,000 to 4,000 psf. The eastern edge of Moody has a high water table, however; thus, soils in that area have different bearing strength. Moody AFB receives a considerable amount of annual precipitation, but because of the level topography (0 to 8% grade) and predominantly thick vegetation, the soils on and near the base are not particularly susceptible to erosion. In unusual cases, wind erosion can occur in dry periods where sandy soils have been cultivated (USAF, 1978a).

3.2.1.5.3 Minerals. There are no mineral occurrences with economic potential in either Lanier County or Lowndes County (Cook, 1978).

3.2.1.6 Natural Disasters

3.2.1.6.1 Earthquakes. Two earthquakes were recorded in south central Georgia between 1826 and 1976. In 1928, one quake was centered close to the town of Valdosta, approximately 15 miles southwest of Moody AFB. In 1958, another was centered about 35 miles northwest of the base. Both were designated of slight intensity on the modified Mercalli scale. According to the Structural Geology Map of Georgia, no apparent faults occur in the Tifton Upland District.

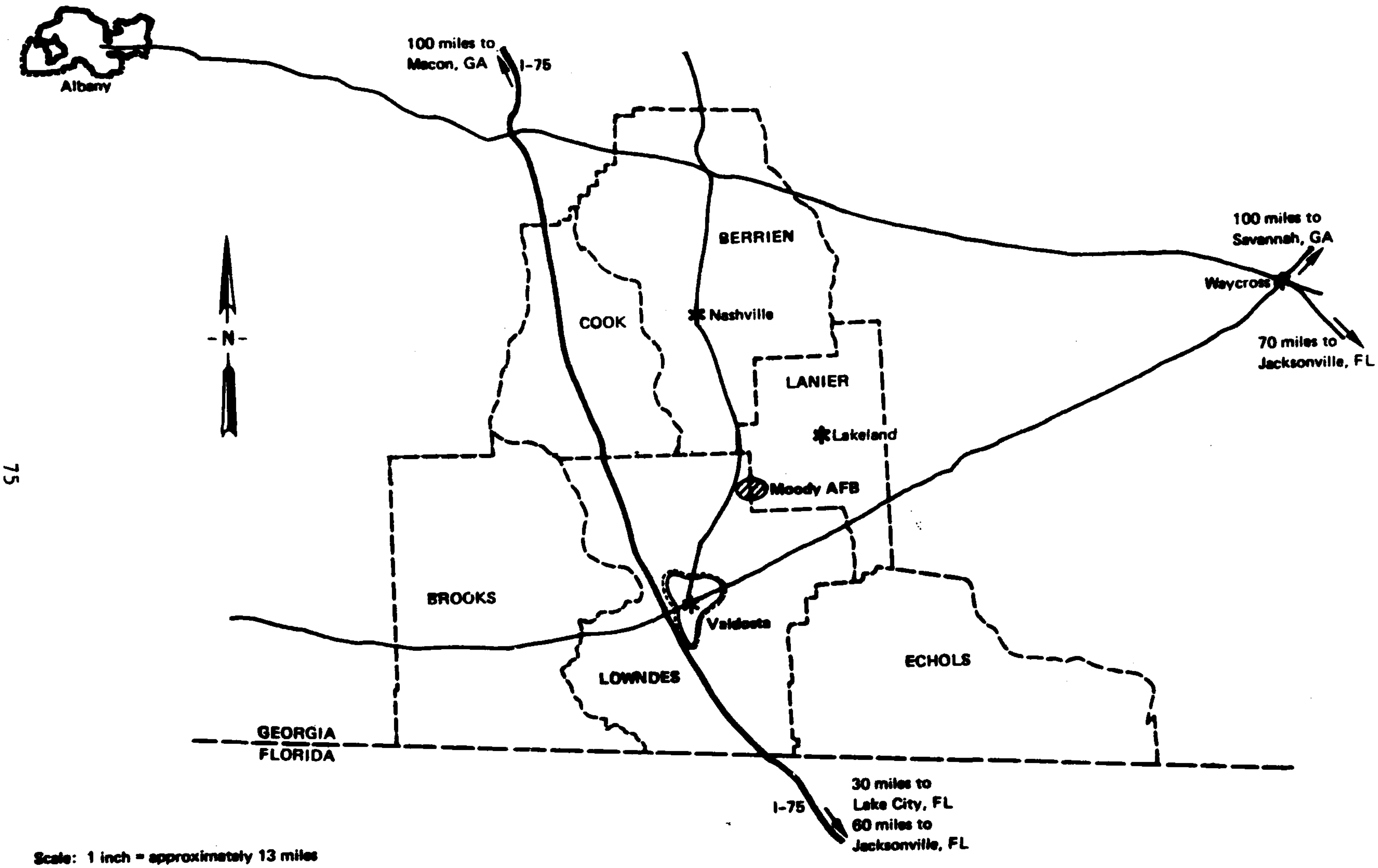
3.2.1.6.2 Fires. Forest fires tend to occur around Moody AFB during dry fall months. In late winter and early spring, farmers burn their fields.

3.2.1.6.3 Floods. The eastern edge of Moody AFB borders Grand Bay Swamp; scattered areas there are swampy and subject to flooding. However, 100- and 500-yr floodplain contours have not been determined for Moody AFB.

3.2.1.6.4 Storms. Moody AFB has been affected in the past by hurricanes, tornadoes, and thunderstorms producing damaging winds and hail (USAF, 1978a). Tornadoes occur most frequently during the spring; late summer and early fall is the hurricane season. Southern Georgia experiences an average of five tornadoes a year. An average of nine tropical storms, some of which become hurricanes, occurs over the Atlantic Ocean annually. Few of these affect the inland region around Moody AFB. Potentially damaging winds (i.e., greater than 39 knots) occur at Moody three times a year on average.

3.2.2 Socioeconomic Environment

Moody AFB is located about 10 miles northeast of Valdosta, Georgia (see Figure 3-6). The most intensely developed part of the base is located in the northeast corner of Lowndes County; the eastern and lesser developed portions of the base, including parts of the proposed alternate site for PAVE PAWS, are located in Lanier County.



Scale: 1 inch = approximately 13 miles

FIGURE 3-6 MOODY AIR FORCE BASE REGION

Construction and operation of SEPP will affect areas that have the strongest economic ties with Moody AFB. Table 3-16 shows that 88% of the personnel at Moody AFB live in Lowndes County, which represents 91% of the military and 66% of the civilians. For this analysis Lowndes County, including its dominant city, Valdosta, is defined as the ROI.

3.2.2.1 Employment

The economy of the ROI is well balanced. The percentages of total nonmilitary employment in the major sectors of the economy are as follows: manufacturing--24%; wholesale and retail trade--26%; services and finance, real estate, and insurance--17%; and federal--18%.

Valdosta is a secondary trade center within the 27-county Albany economic area, defined by the U.S. Department of Commerce, Bureau of Economic Analysis. The Valdosta labor market area encompasses Lowndes and the five surrounding Georgia counties, as well as parts of five other counties in Georgia and Florida (South Georgia Area Planning and Development Commission, 1981).

With about 3,500 personnel, Moody AFB is the largest employer in the ROI (see Table 3-17); civilian employment at the base in September 1981 was 726. Between 1976 and 1981 the number of personnel at Moody AFB averaged 3,470; in the last 3 years of that period, the number of assigned personnel did not vary by more than 20. In FY 82 Moody AFB will take on an additional 500 military personnel (see Table 3-18).

Table 3-16

MOODY AFB: WORK FORCE BY COUNTY OF RESIDENCE[a]

County	Military	Civilian	Total	Percent
Lowndes	2,529	303	2,832	88
Berrien	168	71	239	7
Lanier	54	38	92	3
All other counties	19	46	65	2
Total	2,770	458	3,228	100

[a]As of October 3, 1981.

Source: USAF (1982f).

Table 3-17

MOODY AFB: PERSONNEL BY YEAR, 1976 TO 1981

	1976 June 30	1977 March 31	1978 Sept. 30	1979 Sept. 30	1980 Sept. 30	1981 Sept. 30
Appropriated						
Military	2,460	2,842	2,870	2,731	2,756	2,732
Civilian	539	497	473	473	464	461
Nonappropriated	91	112	118	111	123	125
Contract	125	93	172	172	140	140
Total	3,215	3,544	3,633	3,487	3,483	3,458

Sources: USAF (1977, 1978c, 1979d, 1980b, 1981c, 1982f).

Table 3-18

MOODY AFB: PROJECTION OF AUTHORIZED PERSONNEL

	FY 81	FY 82	FY 83	FY 84
Military				
Officers	356	406	407	405
Enlisted	2,399	2,860	2,883	2,890
Civilian[a]	552	567	567	567
Total	3,307	3,833	3,857	3,862

[a]Only authorized personnel are included. In FY 82 there were 1,432 additional civilian personnel: nonappropriated fund personnel, contract personnel, and employees of other on-base businesses.

Source: Carswell (1982).

Between FY 82 and FY 84 the number of authorized positions at Moody AFB is expected to remain relatively constant.

In 1980 the 12 largest manufacturers in the ROI employed about 4,200 people; 900 were employed by Levi Strauss & Co. (Georgia Department of Industry and Trade). Between 1978 and 1981 the civilian employment in the ROI increased by 5% to 26,557. By June 1982 employment had declined by 91 jobs. The Valdosta area is expected to grow at its historic rate; no dynamic new development in the near future is expected (South Georgia Area Planning and Development Commission, 1981).

Between 1976 and 1980 the unemployment rate in the ROI was less than the state average. Since that time, the unemployment rates in the state and in the ROI have been relatively equal. In 1981 the average unemployment rate in the ROI was 6.7%. In June 1982 the rate was 7.2% and in the state it was 8.1%.

3.2.2.2 Population

The population of the ROI was about 68,000 in 1980 (see Table 3-19). During the 1970s, it grew at an average annual rate of 2.3%, or slightly more than Georgia's growth rate during the same period. About 55% of the ROI population resides in Valdosta, which grew about 1.6%/yr during the 1970s.

Although no formally accepted population projections for the ROI exist, growth during the 1980s is expected to approximate that of the previous decade (South Georgia Area Planning and Development Commission, 1981).

Between May and December 1982, the number of personnel at Moody AFB is expected to increase by 500. This alone could increase the population in the ROI by more than 2%.

Table 3-19

MOODY AFB: ROI POPULATION, 1950 TO 1980

	Population				Percent Change	
	1950	1960	1970	1980	1960-1970	1970-1980
Lowndes County (ROI)	35,211	49,270	55,112	67,972	11.9	23.3
Valdosta	20,046	20,652	32,303	37,596	5.4	16.4
Georgia					14.5	19.1

Source: U.S. Census Bureau (1981b).

3.2.2.3 Income

Per capita income in the ROI was $6,486 in 1979, which is 85% of the Georgia average and 74% of the U.S. average (see Table 3-20). Between 1974 and 1979, per capita income in the ROI grew 63%, which is comparable to the increase in Georgia and the United States. During that same period, total personal income in the ROI increased 61%; in Georgia and the United States it increased by 68%.

3.2.2.4 Housing

Housing stock in the ROI increased rapidly during the 1970s, more than one and a half times the population growth (see Table 3-21). At the same time the average household size decreased from 3.17 to 2.79.

Since 1980 the growth rate the housing stock in the ROI, as in most regions of the United States, has decreased. Between January 1980 and June 1982, 1,258 housing permits were issued in Lowndes County (Northcutt, 1982). (This includes permits issued in Valdosta and unincorporated areas of Lowndes County; it excludes Hahira, Naylor, Dasher, Lake Park, and Remerton, which comprised 4.9% of the county population in 1980). Representatives of the local real estate industry and governmental agencies believe that pent-up demand for housing is

Table 3-20

MOODY AFB: ROI PER CAPITA INCOME, 1974 AND 1979

	1974 (dollars)	1979 (dollars)	Change (percent)	Percent of U.S.
ROI (Lowndes County)	4,061	6,486	63	74
Georgia	4,753	7,627	60	87
Southeast region[a]	4,191	6,251	49	71
United States	5,428	8,757	61	--

[a] Southeast region includes Arkansas, Louisiana, Mississippi, Alabama, Tennessee, Georgia, Florida, South Carolina, North Carolina, Virginia, West Virginia, and Kentucky.

Source: U.S. Department of Commerce (1981).

Table 3-21

MOODY AFB: ROI HOUSING STOCK, 1970 AND 1980

	Housing Units 1970	Housing Units 1980	Housing Units Change (percent)	Population Change, 1970-1980 (percent)
Lowndes County	17,404	24,333	39.8	23.3
Valdosta	10,548	13,665	29.6	16.4

Source: U.S. Census Bureau (1981b).

strong and that many developers will start projects when interest rates decrease to an acceptable level (Northcutt, 1982; Anthony, 1982).

The vacancy rates in 1980 are enumerated in Table 3-22. Although more recent figures are unavailable, the vacancy rate is now probably lower than the 1980 level for rentals and higher for owner-occupied homes. Because of high interest rates and lack of building in recent years, people who might normally buy housing seek rentals. In July 1982 about 500 homes were listed for sale on the multiple listings in Valdosta; the typical number is 400 (Anthony, 1982). The rental market is described as tight, likely to have less than 5% vacancies, but not critical (Anthony, 1982). Representatives of the Moody AFB housing referral office state that a shortage of apartments and mobile homes for rent exists, but that military personnel are finding places to rent (Bland, 1982b).

In 1980 the median value of homes in Lowndes County was $35,500 (U.S. Census Bureau, 1982). Value has appreciated little since that time (Anthony, 1982). A typical 2-bedroom, 1-bath apartment rents for about $175 to $200, a 3-bedroom, 2-bath apartment rents for less than $300, and a typical house of the same size rents for $325 to $375 (Anthony, 1982; Bland, 1982a). Rents have appreciated 10 to 15% over the past 2 years and are expected to continue to increase under tight market conditions.

On-base housing resources for permanently assigned military personnel consist of 306 family units, 49 mobile home spaces, and 750 dorm beds. In May 1982 the waiting list for family housing was comprised of 4 officers (30-day wait) and 243 eligible enlisted men (10-month wait). Many senior personnel (typically E-8s and 9s and senior officers) seek housing off base. Nearly all E-6s and below seek on-base housing or

Table 3-22

MOODY AFB: ROI HOUSING STOCK AND VACANCY RATES, 1980

	Owner Occupied			Rental		
	Occupied	Vacant, For Sale	Vacancy Rate (percent)	Occupied	Vacant, For Rent	Vacancy Rate (percent)
Lowndes County (ROI)	10,265	192	1.8	7,795	817	9.5
Valdosta	6,130	118	1.9	5,635	516	8.4

Source: *U.S. Census Bureau* (1982).

rent off base. Ineligible enlisted men have the greatest problem obtaining adequate housing.

The ROI contains approximately 2,000 motel rooms. Most of these are located along Interstate Highway 75 near Valdosta.

3.2.2.5 Education System

Lowndes County contains two school districts. The Valdosta City School District is responsible for educating all children residing in Valdosta, and the Lowndes County School District handles all school children living within the county boundaries but outside Valdosta limits.

The Valdosta City School District contains nine schools. Table 3-23 presents the enrollment during the 1981-82 school year and capacity for each school in the district. Of the total district enrollment of 6,532 students, 462 (7%) are children of AF personnel. Each elementary school could accommodate about 50 additional students. The junior high and high schools have room for 150 and 200 students, respectively. Enrollment is expected to remain stable over the next few years.

Table 3-24 presents current enrollment and capacity figures for the nine schools in the Lowndes County School District. About 13% (886 students) of the total district enrollment of 6,805 students are children of AF personnel. Excess capacity exists in all schools in the district. Enrollment declines caused the closure of Westside Elementary School last year. Enrollment is expected to continue to decline over the next 5 years, resulting in a total loss over this period of about 1,000 students. No additional school closures are anticipated at this time, however.

Table 3-23

VALDOSTA CITY SCHOOL DISTRICT ENROLLMENT, 1981-82

School	Total Enrollment	Capacity
Elementary schools		
Lomas-Pinevale (K-4)	813	863
Sallas-Mahone (K-4)	613	663
S.L. Mason (K-4)	545	595
West Gordon (5-6)	553	603
W.G. Nunn (K-4)	589	639
Southeast (5-6)	545	595
Valdosta Junior High (7-8)	1,091	1,241
Valdosta High (9-12)	1,730	1,930
South Street Education Center (for the trainable mentally retarded)	53	53
Total	6,532	7,182

Source: Brandon (1982).

3.2.2.6 Community Facilities and Services

Valdosta has primary responsibility for providing public services and facilities to city and county residents. Services provided by Lowndes County are limited to garbage collection from specified sites in the county and maintenance of water and sewer systems that have been donated to the county by the developers. There are no significant facility and service deficiencies.

3.2.2.7 Land Use

The proposed alternate site for the SEPP is east of Moody AFB on lands owned and administered by the U.S. Forest Service (USFS) but controlled by Moody AFB. The USAF and USFS have a memo of understanding that permits Moody AFB to use particular portions of the area, including the proposed site. The USFS also permits the State of Georgia to use much of the area for public hunting. The USFS has classified the 9,300 acres east of Moody AFB as excess. Although disposal proceedings have started, the land will not be released without full protection of USAF interests (Grandy, 1982). An abandoned landing field on the site

Table 3-24

LOWNDES COUNTY SCHOOL DISTRICT ENROLLMENT, 1981-82

School (Grade)	Total Enrollment	Children of AF Personnel	Capacity
Elementary schools			
Clyettville (K-5)	406	5	550
Hahira (K-5)	537	46	725
Lake Park (K-5)	618	27	1,075
Parker Mathis (K-5)	437	14	550
Pine Grove (K-2)	433	148	600
Pine Grove (3-5)	454	201	485
Middle schools			
Hahira (6-8)	787	181	980
Lowndes (6-8)	960	26	1,092
Lowndes High (9-12)	2,173	238	2,772
Total	6,805	886	8,829

Source: Sears (1982).

is used occasionally by the USAF to jettison excess fuel. The site is bisected by the east-west boundary line of Lanier and Lowndes counties (see Figure 3-7).

Figure 3-7 also depicts the area that would be scanned by the radar, a sparsely populated area that is primarily swamp, forest, and farm land. To the rear of the radar is Banks Lake (2.4 miles to the north), parts of Grand Bay (to the northwest), and the developed portion of Moody AFB (3.4 miles to the northwest).

Less than 20% of the land in the scan sector and within 2 miles of the site is used for crops. About 35 structures are located in this area. Most farms are clustered along the southeastern side of Highway 211. The closest farm is about 0.7 mile from the site. Land holdings in the area are small (less than 10 to a few hundred acres), with most in the 50- to 150-acre category.

Land use around the site is not expected to change in the foreseeable future. About 80% of Lanier County's 5,654 residents live in the Lakeland census division to the north and east of Banks Lake. Residential growth in the county is in Lakeland and along Highway 125 south of Ray City, where some 10- to 30-acre farm homes and 1- to 2-acre homes have been developed (Colston, 1982).

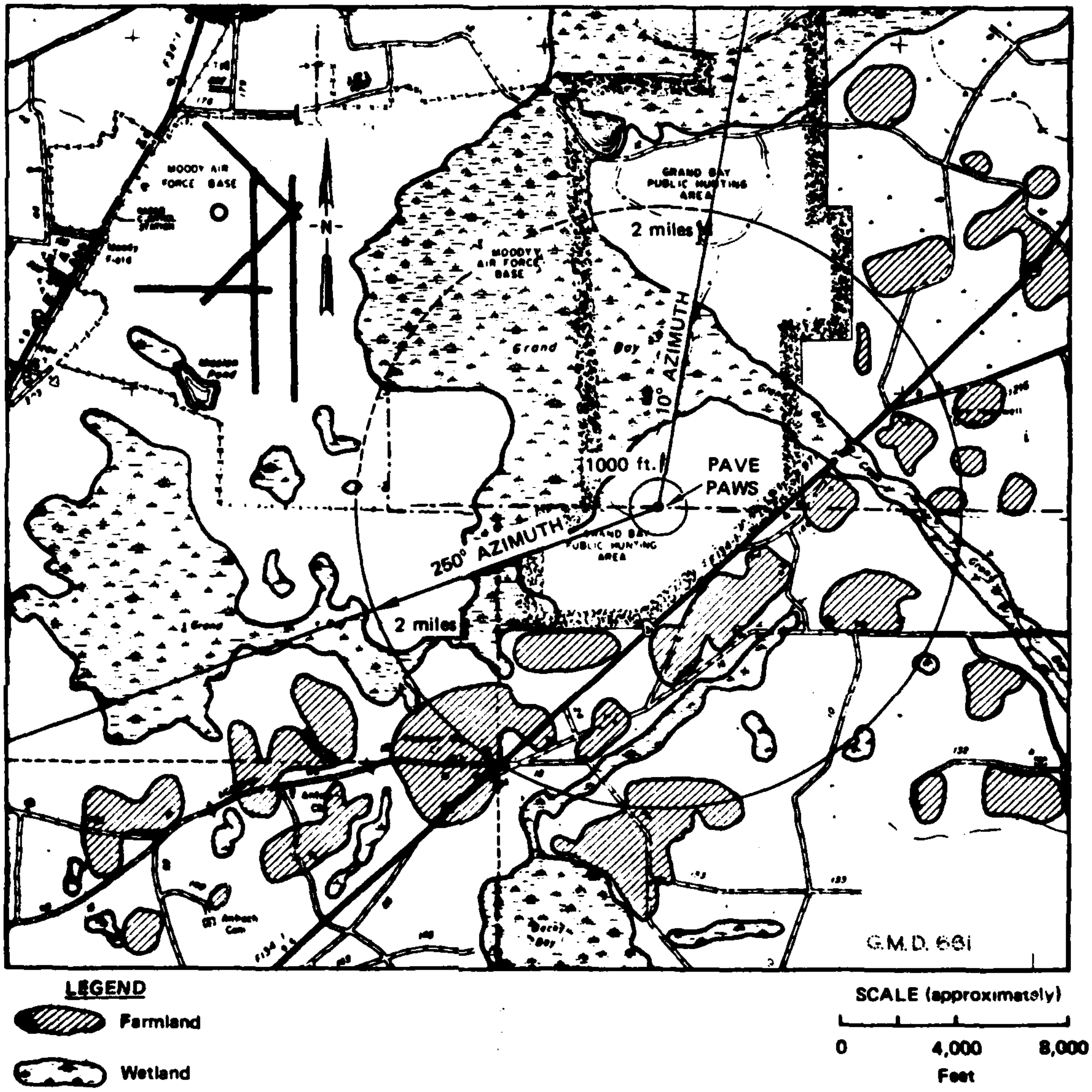


FIGURE 3-7 MOODY AIR FORCE BASE VICINITY LAND USE

The Lowndes County areas around the site are zoned agricultural-residential. According to the zoning ordinance, this categorization is designed "to provide areas for agricultural uses, said areas being protected from the depreciating effect of small residential lot development and from encroachment of those uses which are incompatible to a desirable agricultural or low density residential environment."

3.2.2.8 Aesthetics

The proposed site is at the junction of two abandoned runways. The site and the runways were paved in the 1940s, but 1-ft high grass has penetrated the decomposing pavement. A dense forest with 40- to 50-ft pines surrounds the runways. Because of the flat terrain and forest, the site is not visible from off-site locations. The only views of the site are afforded by a public jeep trail that leads to the Grand Bay and Banks Lake area as well as the back gate of Moody AFB. This trail crosses the site itself.

3.2.2.9 Cultural Resources

A survey was conducted of the PAVE PAWS site to determine the presence or absence of cultural resources that might be affected by the proposed construction. Prior to the cultural resource survey, a search of the Georgia Archeological Site Files at the University of Georgia was initiated. The search indicated no recorded archeological sites near the project area.

The cultural resource survey found no archeological sites within the proposed 10-acre PAVE PAWS facility area or the 60-acre safety zone. The area has been subjected to intensive disturbance in the twentieth century from the construction of a paved runway associated with Moody AFB. If any cultural resources existed, they were effectively destroyed during runway construction.

The survey did discover prehistoric artifacts lightly scattered in a plowed field southeast of the proposed site. Seven pieces of chert debitage and three of silicified coral were found scattered over the area, with no apparent concentrations. No diagnostic artifacts were recovered. Since the artifacts were clearly outside the PAVE PAWS site, no testing was conducted.

3.3 MacDill AFB (Radar Closure)

3.3.1 Biophysical Environment

The AN/FSS-7 radar facility at MacDill AFB is located on the less developed southeastern corner of the base, approximately 100 ft from the shore of Hillsborough Bay at the tip of the Interbay Peninsula. The topography of MacDill AFB and the surrounding region is known as flatwood, i.e., a prehistoric bay bottom typically vegetated with pine and palmetto (cabbage palm) forests. Flatwood areas generally have a high water table, are periodically flooded, and contain scattered lakes,

ponds, cypress domes, and river swamps. Mangrove, bermuda grass, and slash pine are also found on MacDill AFB.

No federal or state listed threatened or endangered plant species are on the base, although the mangrove swamps are identified as Vital Areas in the Florida Coastal Zone Management Plan (USAF, 1979a). One threatened animal species sighted in the swamps and on the golf course at MacDill AFB is the American alligator (Alligator Mississippiensis). Two transient endangered species also sighted on the base are the southern bald eagle (Haliaeetirs lencocephalas) and the brown pelican (Pelecanus occidentalis). The latter species is being withdrawn from the federal list (Blonshine, 1982).

The base also provides habitat for a variety of small animals (opossum, rabbit, fox, raccoon, and weasel), predatory birds (vulture, hawk, osprey, and owl), and small birds (hummingbirds, whippoorwills, mockingbirds, and meadowlarks).

The Southeast Florida Intrastate AQCR, which includes MacDill AFB, has ambient air quality levels of sulfur oxides, nitrogen dioxide, and carbon monoxide in compliance with federal and state standards. However, a portion of Hillsborough County fairly close to the base is a nonattainment area for federal secondary particulate standards due to fugitive industrial process emissions and fugitive urban dust (Garvey and Streets, 1980). Photo-oxidant levels are also in violation of federal standards in all of Hillsborough County. As of January 1977, ambient air quality levels of particulates and sulfur dioxide measured at an on-base sampling station near the AN/FSS-7 radar were in compliance with standards.

The major sources of air pollutant emissions on MacDill AFB are road vehicles, including aerospace ground equipment and heavy equipment (45%), aircraft (41%), evaporation (9%), special processes (3%), fuel combustion (0.7%), and incineration (0.04%). By weight, pollutants emitted are carbon monoxide (63%), hydrocarbons (21%), nitrogen oxides (9%), particulates (4%), and sulfur oxides (2%).

The principal aircraft that operate from MacDill AFB are listed in Table 3-25. The AN/FSS-7 radar is surrounded by flight tracks but has a day-night average sound level less than 65 dBA.

At MacDill AFB the water table lies from 1 to 4 ft below the ground. The base, however, purchases water from the City of Tampa, which, in turn, obtains its supply from surface aquifer wells. Due to salt water intrusion problems, depletion of the water table, and increasing local demand for water, a new regional water supply system is being planned. The system will entail drilling a new well field in the Hillsborough River basin where the aquifer is estimated to have an indefinite life. The water supply system to the base has a maximum capacity of 36 mgpd; water demand on the base has not exceeded 3 mgpd (USAF, 1979a).

Table 3-25

AIRCRAFT OPERATIONS DURING AVERAGE BUSY DAY: MACDILL AFB

Type of Aircraft	Number of Takeoffs/Landings
F-16	80
U-21	1
C-12	1
O-2	1
UH-1	3
Total	86

The sanitary sewage treatment facility on MacDill AFB can accommodate up to 1.2 mgpd of wastewater; its current use averages less than 75% of capacity, even with input from industrial sources on base. Secondary treatment plus aeration are provided. The plant puts zero discharge into the bay because the effluent is used for irrigating the base golf course and for watering 125 acres of pine forest and bermuda grass. The sanitary sewer system could accommodate a "future increase mission of unknown size," as long as no discharge connections are made to the storm sewers on base (USAF, 1979a). The surface runoff system on MacDill AFB currently drains into Hillsborough Bay on the east and Tampa Bay on the south and west.

In addition to being highly acidic, surface soils in the vicinity of MacDill AFB are medium to fine sand; a thin layer of hardpan (solid subsoil) lies below ground surface at varying depths. With the exception of the swampy areas, the design bearing strength of the soil on the base is 1,500 psf. The soils are not susceptible to wind or water erosion.

MacDill AFB is potentially vulnerable to hurricanes, tornadoes, waterspouts, and thunderstorms with lightning. The hurricane season is June through November, but the base has never been directly in the path of such a storm. Hurricanes, waterspouts, and heavy thunderstorms result in local flooding--the flood level for 10-yr storms is 12-13 ft and that for 100-yr storms is 14.5-15 ft. MacDill AFB's low elevation and location make it particularly susceptible to wave damage and flooding. Since 1965, the base has been struck by tornadoes several times.

3.3.2 Socioeconomic Environment

The ROI for MacDill AFB is Hillsborough and Pinella counties. As shown in Table 3-26, more than 95% of Detachment 1 personnel (including personnel living on the base) and most other base personnel reside in Hillsborough and Pinellas counties.

Table 3-26

MACDILL AFB: PERSONNEL BY PLACE OF RESIDENCE, 1982

	Detachment 1 Personnel (%)	MacDill AFB (all units) Personnel (%)
MacDill AFB (Hillsborough County)	25 (38)	2,325 (35)
Greater Tampa (Hillsborough County)	32 (49)	3,255 (49)
St. Petersburg/Clearwater (Pinellas County)	6 (9)	465 (7)
Other Florida communities	3 (4)	577 (9)
Total	66	6,642

Sources: USAF (1982e and 1982g).

Hillsborough and Pinellas are two of the four counties comprising the Tampa Bay Region. Population in the region grew substantially during the 1970s; this trend is projected to continue, with an increase from an estimated 1,698,000 in 1980 to 2,173,000 by 1990. Approximately three-quarters of this growth will occur in Hillsborough and Pinellas counties, as shown in Table 3-27. A substantial growth in the housing stock accompanied the 1970s population growth (see Table 3-28).

The economic base of the Tampa Bay Region is diverse, consisting of a wide range of industrial activities, as well as construction, agriculture, and tourism. Current employment in the region numbers 741,521. Hillsborough and Pinellas counties account for approximately 80% of this total employment (see Table 3-29). Industrial development and diversification is projected to continue during the next 10 years. There are no known sites of historical or archeological significance within the boundaries of MacDill AFB (USAF, 1979a).

3.4 Eglin AFB

3.4.1 Biophysical Environment

Eglin AFB is within the Coastal Plains physiographic province. It contains coastal lowlands and western highlands topography with sandhills, upland and lowland forests, grasslands, swamps, and numerous streambeds, lakes, and ponds. Of the 463,000 acres on the base, 406,000 are under forest management, and 45% of those are intensively managed. Approximately 20,400 acres are considered of botanical significance,

Table 3-27

MACDILL AFB: ROI POPULATION, 1980-1990

	1980	1982	1985	1990
Hillsborough County	646,960	670,500	715,900	781,700
Pinellas County	728,531	759,400	819,000	905,600
Total ROI	1,375,491	1,429,900	1,534,900	1,687,300

Source: University of Florida (1981).

Table 3-28

MACDILL AFB: NUMBER OF HOUSING UNITS IN ROI

	1970	1980	Percent Change, 1970-80
Hillsborough County	168,555	263,619	56.4
Pinellas County	228,771	376,971	64.8

Source: U.S. Census Bureau (1981a).

Table 3-29

MACDILL AFB: ROI LABOR FORCE CHARACTERISTICS, 1982

	Labor Force	Employment	Unemployment	Unemployment Rate (percent)
Hillsborough County	350,546	322,706	27,840	7.9
Pinellas County	300,016	279,664	20,352	6.8

Source: Florida Department of Labor and Employment Security (1982).

including a ravine forest and a prairie pond. In the southeastern corner of the base, the AN/FPS-85 radar is surrounded by sandhills, reforested areas, and surface water courses (i.e., floodplain areas).

Longleaf pine is the predominant vegetation on Eglin AFB, although scrub oak and other deciduous trees, wet pine-barren flora, cypress, and black gum also occur. Seven plants listed as threatened by the State of Florida are found on the base (USAF, 1979b). Plant associations in the vicinity of the radar are sand pine/turkey oak, turkey oak/sand pine/longleaf pine, and turkey oak/longleaf pine.

Small animals living throughout the base are snakes, toads, tortoises, turtles, lizards, and gophers. White-tailed deer, black bear, wild hog, and Florida panther are also common. A variety of vultures, hawks, and owls frequent Eglin AFB, as do many small game and song birds. A total of 52 species of fish have been identified in the water courses on the base.

Eglin AFB is within the range of quite a few rare, endangered, and threatened animal species, including three on the federal endangered list. Red-cockaded woodpecker (Picoides borealis) cavity trees are known to be just to the north of the radar site. In addition, to the east of the radar, locations of the pine barrens treefrog (Hyla andersonii) have been identified; this species, however, will be removed from the list (Wolfgang, 1982). The okaloosa darter (Etheostoma okaloosae) habitat on the base is considerably west of the radar. One federal threatened species living in the creeks, ponds, and swamps on Eglin AFB is the American alligator (Alligator mississippiensis); the swamp area south of the radar may provide suitable habitat for it (Wolfgang, 1982). Another federally listed threatened species is the eastern indigo snake (Drymarchon corais couperi), which inhabits sandy soil areas. Many state listed species also reside on Eglin (USAF, Readiness Command).

Eglin AFB is located in the Mobile-Pensacola-Panama City-Southern Mississippi Interstate AQCR. In certain portions of the region, particulate, sulfur oxide, and photochemical oxidant levels are in excess of federal standards. The three counties that encompass the base, however, are in attainment of standards for the five regulated pollutants (Garvey and Streets, 1980). There are no permanent sampling stations on the base.

The major sources of air pollutant emissions are vehicles, namely automobiles and heavy diesel equipment (51%); aircraft operations, maintenance, and ground equipment (43%); evaporation (3%); special processes, including fire training and the asphalt plant (2%); and fuel combustion (1%). Relative pollutant contribution by weight to the local atmosphere is carbon monoxide (62%), hydrocarbons (14%), nitrogen oxides (12%), particulates (10%), and sulfur oxides (2%).

Noise is generated on Eglin AFB by aircraft, weaponry testing, and vehicle traffic. The principal aircraft operating from the base are listed in Table 3-30. The radar is beyond the main base runway area and therefore is in a noise contour with a day-night average sound level less than 65 dBA. Bombing and target practice does take place around the radar site, however.

The waters of northwest Florida are relatively uncontaminated. Groundwater is located in three principal aquifers below Eglin AFB: in the sand and gravel aquifer (under the western portion), in the upper limestone of the Floridan aquifer (under the eastern and central portion), and in the lower limestone of the Floridan aquifer. Local groundwater movement is in a southwesterly direction. The radar obtains its

Table 3-30

EGLIN AFB: ANNUAL AIRCRAFT OPERATIONS

Type of Aircraft	Number of Takeoffs/Landings Per Year (1979)
F-111	416
F-15	13,234
A-7	588
C-135	112
C-141	192
C-130	2,060
F-4	4,103
T-39	2,296
T-38	5,160
DC-9	5,747
Other	8,413
Total	42,321

water supply from two wells in the upper limestone aquifer, which is under artesian pressure and which provides relatively pure water that requires only chlorine treatment. The first well, at 440 ft, provides 250 gpm and the second, at 510 ft, provides 330 gpm. The raw and condensed water is periodically sampled and evaluated at the site.

All surface streams on Eglin AFB have been designated Class I (public water supply) by the Florida Department of Environmental Regulation. Surface water drains primarily into the bayous of Choctawhatchee Bay through agricultural and timber areas. A continuous monitoring program assures that surface runoff of toxic substances associated with weapons testing does not contaminate local streams.

A sanitary sewage plant serves the main base and housing area, provides secondary treatment, and disposes of effluent by spray irrigation of elevated land areas. The AN/FPS-85 facility has its own wastewater treatment facility with a spray field and holding ponds.

The bedrock in the Eglin area is limestone, with the uppermost layer occurring at about 400 ft below the surface. In general, local soils are excessively drained sands that are coarse in texture, low in organic matter, and low in moisture holding ability. Clay and gravel lenses lie below the surface sands. The primary soil association at the AN/FPS-85 site is Lakeland, which is characterized by dark to light gray sandy surface layers and brownish-yellow sandy subsoils more than 80 in. deep. No documentation is available on the bearing strength of the soil on Eglin AFB.

No known earthquake faults are in the area. On the basis of historical experience, it is estimated that a hurricane will affect the base every 6 years. Hurricane-spawned tornadoes, winds, rains, and storm surge are also local hazards. Both a 1965 hurricane and a major windstorm in the late 1970s detached the face of the AN/FPS-85 radar. As a contingency measure, when winds in excess of 50 mph occur at the site, a large vacuum pump is used to create pressure to keep the radar face attached. In 1979, Hurricane Frederick swerved at the last minute toward Mobile, Alabama, just avoiding Eglin AFB.

3.4.2 Socioeconomic Environment

The ROI around Eglin AFB is Okaloosa County. As shown in Table 3-31, all of the Detachment personnel reside in the county.

Okaloosa County experienced substantial population growth during the past decade, a trend that is expected to continue; the 1980 population of 109,920 is projected to increase to 128,500 by 1990. This population growth, coupled with a decrease in average household size, has produced a corresponding increase in the county's housing stock. Tables 3-32 and 3-33 summarize the population and housing characteristics of the county.

Table 3-31

EGLIN AFB: PLACE OF RESIDENCE FOR 20th MWS, 2159 CS, AND AFLC PERSONNEL, 1982

Place of Residence	Number of Personnel
Okaloosa County (off-base)	288
Eglin AFB (on-base)	100
Total	388

Source: King (1982).

Table 3-32

EGLIN AFB: ROI POPULATION AND HOUSING CHARACTERISTICS

Okaloosa County (ROI)	1970	1980	Percent Change, 1970-80
Population	88,187	109,920	24.6
Number of housing units	27,296	43,099	57.9

Source: U.S. Bureau of the Census (1981a).

Table 3-33

EGLIN AFB: ROI POPULATION PROJECTIONS

Year	Population
1980 census	109,920
1981 estimate	112,873
1983 projection	116,400
1985 projection	120,000
1990 projection	128,500

Source: University of Florida (1982).

Government is the main source of employment in Okaloosa County. Other major employment categories are wholesale and retail trade, services, manufacturing, and construction. A total of 39,114 civilians are employed in the county. The estimated unemployment rate in April 1982 is 7.9% (see Table 3-34). More than 18,000 people are employed at Eglin AFB; about 400 of these are assigned to the Detachment 1 radar (see Table 3-35).

None of the historic or archeologic sites on Eglin AFB is listed on the National Register of Historic Places. However, 34 archeologic sites are registered with the Florida Division of Archives. Of historic interest, 2 of the 19 home sites and 4 of the 25 cemeteries on the base are in the vicinity of the AN/FPS-85. One cemetery is approximately 3 miles north of the radar. Numerous probable archeologic sites also surround the radar, although there are no state recorded (i.e., known) sites in the near vicinity. In June 1982, a 10% archeological survey of the entire base was initiated.

Table 3-34

EGLIN AFB: ROI LABOR FORCE CHARACTERISTICS, 1982

	Persons	Rate (percent)
Total labor force	42,481	-
Employed	39,114	-
Unemployed	3,367	7.9

Source: Florida Department of Labor and Employment Security (1982).

Table 3-35

EGLIN AFB: ASSIGNED AND AUTHORIZED POSITIONS

	Installation Total		20th MWS, 2159 CS and AFLC Personnel	
	Assigned Personnel (Jan. 1982)	Authorized Positions (Jan. 1982)	Assigned Personnel (Aug. 1982)	Authorized Positions (FY 82)
Officers	2,332	2,246		44
Enlisted	11,601	10,433	344	248
Civilians	4,256	4,446	44	46
Total	18,189	17,125	388	338

Sources: King (1982); USAF (1981d).

AD-A129 370 SOUTHEAST PAVE PAWS RADAR SYSTEM ENVIRONMENTAL ASSESSMENT(U) SRI INTERNATIONAL MENLO PARK CA S J EVERETT ET AL. MAR 83 SAM-TR-83-7 F33615-82-C-0604

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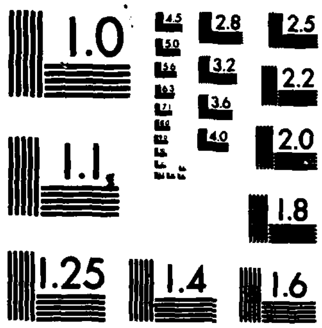

1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

4 ENVIRONMENTAL CONSEQUENCES

4.1 Robins AFB (Proposed Site)

Because the proposed action is operation of the PAVE PAWS radar, the direct impacts on the environment depend primarily on the magnitude, nature, and distribution of the radiofrequency radiation (RFR). A detailed description of the PAVE PAWS radar system is given in Appendix A, and a comprehensive technical description of the resulting RFR is presented in Appendix B. Calculated values in this section are based on the field model described in Appendix B. Comparison of the measured and calculated values at Beale AFB shows that the field model is well-founded and conservative (see Table B-7).

4.1.1 Radiofrequency Radiation (RFR)

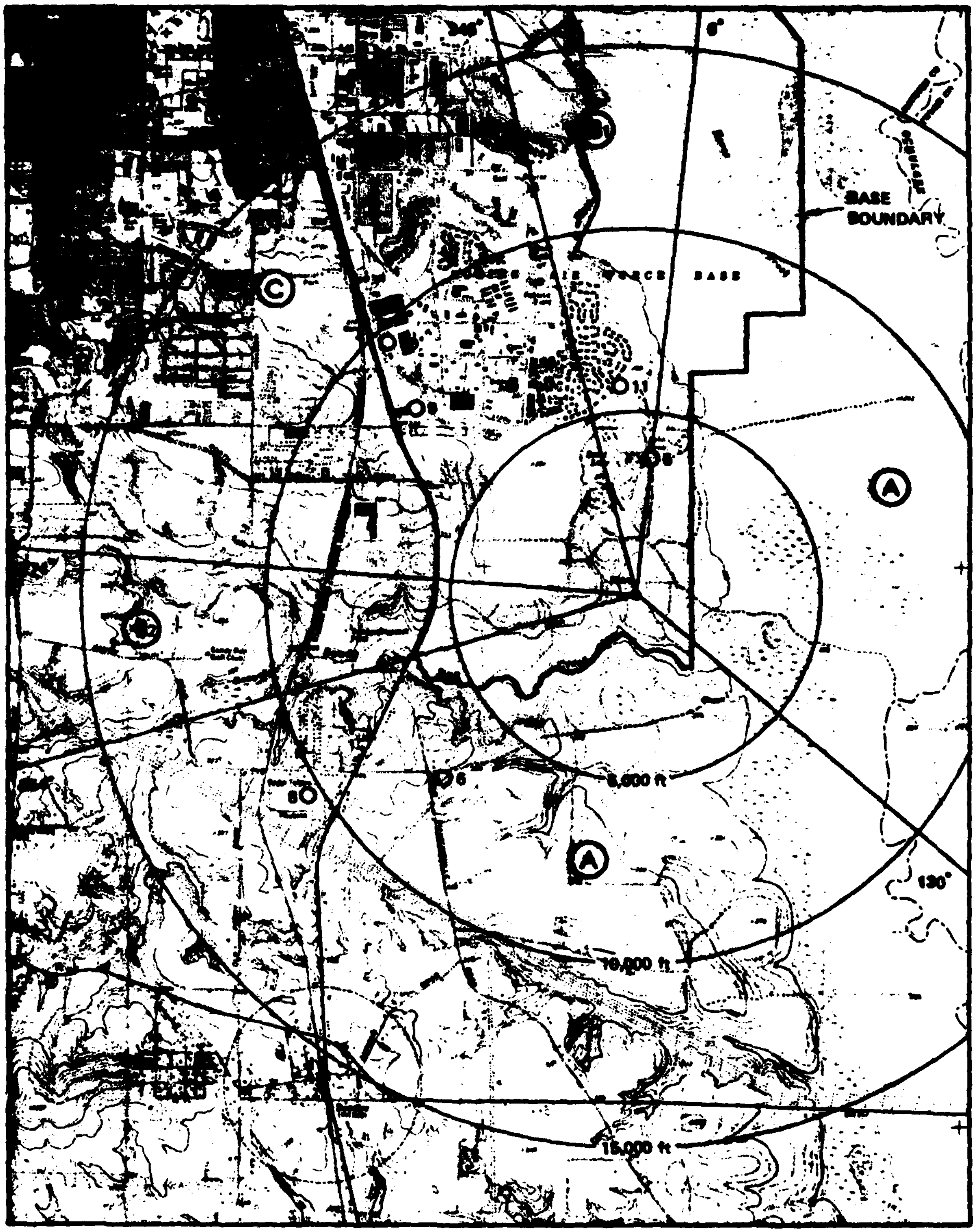
This section describes the power density of the RFR in the immediate vicinity of PAVE PAWS in the main beam and at and near ground level, 200-500 ft above mean sea level. Because the ground is relatively flat, it is never struck by the main beam; therefore, only the first and higher order sidelobes will contribute to the power density of the RFR at ground level in the vicinity of the proposed site. Because the power density increases as the antenna face is approached, the highest ground-level densities that can be encountered without entering the posted exclusion fence area are found just outside the exclusion fence (see Figure 4-1), well within the boundaries of the military reservation.

4.1.1.1 RFR Fields

Time-averaged values of RFR are based on 15% duty cycle (for each face), which is the percentage of time that the system normally radiates for simultaneous operation of both faces. However, some specific effects related to electromagnetic interference depend on the pulse power density and other technical specifications of the individual pulses. For this reason, peak values of power density and electric-field intensity are also given. Appendix A includes details of pulse patterns used.

4.1.1.1.1 Units. A quantitative discussion of the intensity and possible effects of RFR requires use of a set of consistent units. Following common usage, all values of radiation intensity are expressed as power density in milliwatts per square centimeter (mW/cm^2). The unit used for area is square centimeters, which is consistent with the national policy of adopting metric units. Because land surveying is still based on English units, distances and dimensions are expressed in feet (ft). Electric-field intensities are given in volts per meter (V/m), the accepted units for this parameter. The symbol Z is used to identify the angle in degrees between the direction to a particular point and a line perpendicular to the applicable radar face.

4.1.1.1.2 Identification of Sectors. Figure 4-1 shows the immediate vicinity of the proposed PAVE PAWS radar at Robins AFB. The radial lines



SCALE

0 0.5 1.0 1.5
Miles

FIGURE 4-1 RFR ZONES OF PAVE PAWS AT ROBINS AIR FORCE BASE

mark the boundaries of the sectors in which the RFR power density will be described. The power densities in the various sectors differ because of the geometry describing the radar coverage of each face. The first three sidelobes, which follow the main beam, sweep through 120 deg in azimuth centered on each face (240 deg in azimuth overall); the higher order sidelobes, taken together, fill the hemispheres in front of the two faces. These hemispheres overlap in the middle of sector A of Figure 4-1. Thus, the total intensity in this overlap region is taken as double that in the rest of sector A. In sectors B_1 and B_2, the power density is solely attributable to the higher order sidelobes; hence, RFR is relatively low in those sectors. Finally, in sector C, the RFR results only from scattering and diffraction. This is the sector of lowest RFR. Each sector shown is keyed to figures that describe RFR power density in relation to distance from SEPP and to the slope of the ground above or below the radar base. The circles shown in Figure 4-1 denote distance from the radar.

Values of average power density have been calculated for various locations in sectors A, B, and C. The reliability of such calculations is supported in Section B.10 of Appendix B, which presents a comparison of measured and calculated values of RFR for 18 locations near Beale AFB. In no case does the measured value exceed the calculated value by a factor greater than 1.6; this is a very satisfactory agreement because the accuracy of the measuring equipment is limited to an uncertainty factor of 1.6 (multiply or divide by). To be conservative (i.e., overstate estimated values), the calculations do not include attenuation caused by intervening vegetation. Vegetation often reduces power densities by a factor in the range of 10:1 up to 100:1.

4.1.1.1.3 <u>Sector A</u>. Sector A must be divided into two regions--the near and far field. The conventional far field starts at R = 9,200 ft, but no serious error results from considering it to start at 1,850 ft. Calculation of the far field is relatively simple because the analytic conditions are constant, and the power density varies inversely with the square of distance. In the near field the main beam is not well established, and the analysis is more complex. Higher order sidelobes continue to contribute to the RFR in a manner that is insensitive to ground level. In contrast, the RFR contributed by the near-field column or the first three sidelobes is quite sensitive to ground level. To simplify the procedure, we have assumed that RFR values are independent of azimuth in sector A, which tends to understate the expected values near the scan limits. As previously noted, the values are doubled in the 10-deg beam overlap region near 130 deg azimuth.

The results obtained by combining the contributions due to random higher order sidelobes and those of the first three sidelobes associated with the sweeping surveillance beam at an elevation of 3 deg are shown in Figure 4-2, which is also shown in Appendix B. Clearly, the values of power density are sensitive to the (average) slope of the ground. Except for locations quite close to the radar, the average slope is less than 1 deg.

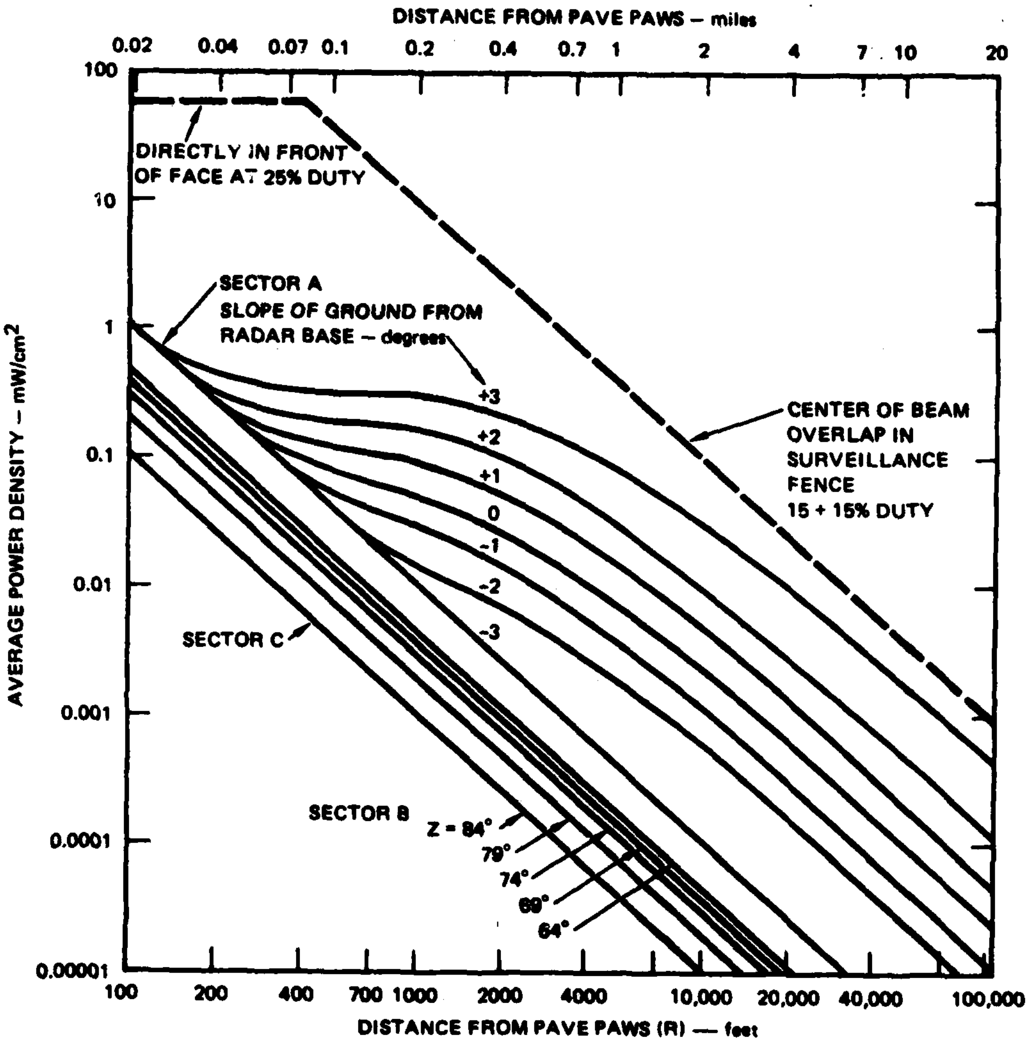


FIGURE 4-2 AVERAGE POWER DENSITIES AT GROUND LEVEL NEAR SEPP

4.1.1.1.4 Sector B. Sectors B_1 and B_2 are characterized by values of RFR that are lower than those of sector A. The main beam and first two sidelobes do not reach these sectors, which are dominated by higher order sidelobes. In these sectors the average power density is insensitive to ground level and is represented by the single equation $U_a = 11{,}000 \cos Z/R^2$, where R is the distance in feet from the nearest face of the radar and Z is the angle away from the boresight axis of that face. This expression is also plotted in Figure 4-2 for the values Z = 64, 69, 74, 79, and 84 deg.

4.1.1.1.5 Sector C. Sector C, the sector with the lowest RFR, is of great interest because it includes the homes and work places of most people who live in the vicinity of Robins AFB. In this sector the only RFR results from scattering and diffraction, because the two faces of the radar are pointed away from this area. Because the RFR is diffuse, its value is insensitive to ground level, and a single curve describes all ranges and elevations in this sector. The governing equation is $U_a = 1{,}100/R^2$. The effects of vegetation, which is likely to reduce these values by a factor of ten, are not included in Figure 4-2.

Figure 4-3 supplements Figure 4-2 by providing values of peak power density and peak electric-field intensities for the same sectors and zones. It too is shown in Appendix B.

4.1.1.1.6 Power Densities at the Exclusion Fence. The exclusion fence is intended to prevent people and some animals from inadvertently approaching closer than about 1,000 ft from the antenna faces. At its perimeter, the fence extends over a sector of 248 deg, slightly greater than the 240-deg sector swept by the cylindrical beam of the near field (see Figures 2-4 and A-1). It extends inward to the corners of the radar building in the configuration shown in Figure 4-4. Although the near-field power density falls rapidly outside the cylinder containing most of the power, it increases rapidly as the antenna face is approached. Consequently, it is important to estimate the power density at various points along the exclusion fence. The power density at ground level in this region is characterized by the calculated values given in Figures 4-2 and 4-3.

Table 4-1 gives the relative azimuths of the four sites identified in Figure 4-4, as well as the average power density and the peak electric field intensity. The values at sites 1 and 2 happen to be equal. Because of beam overlap, the intensity at site 4 is somewhat higher; it represents the highest levels of RFR to which the general public will be exposed. All values are at or near ground level and neglect any attenuation that might result from trees or underbrush.

4.1.1.1.7 Power Densities at Selected Sites. Using the methodology described above, we have developed power densities at several sites in the vicinity of SEPP. These locations were selected because of expressed concerns or because they are places where substantial numbers of people are likely to congregate; they are identified by the numbers 5 through

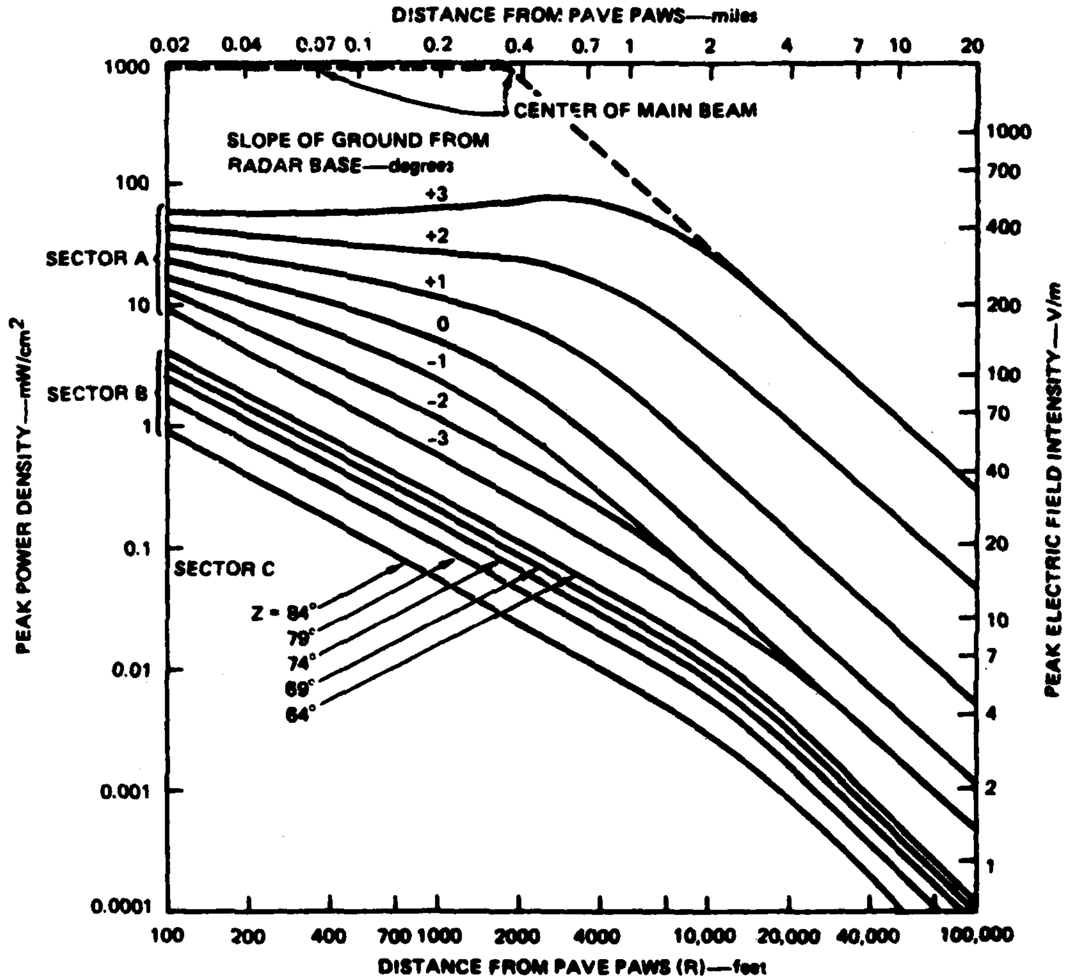


FIGURE 4-3 PEAK POWER DENSITIES AND ELECTRIC FIELD INTENSITIES AT GROUND LEVEL NEAR SEPP

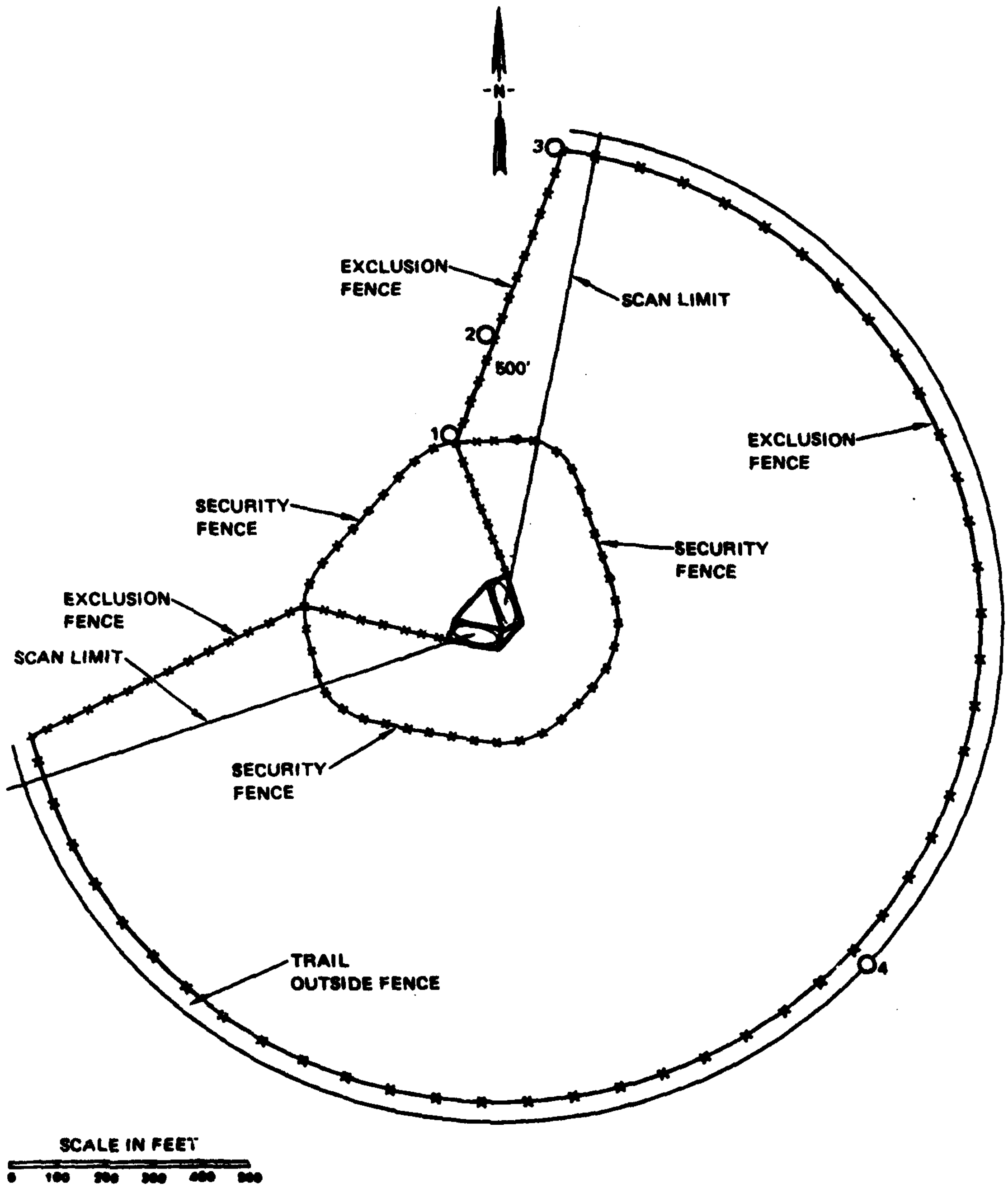


FIGURE 4-4 SECURITY AND EXCLUSION FENCES OF SEPP

Table 4-1

CALCULATED VALUES OF GROUND LEVEL RFR AT THE EXCLUSION FENCE

Site No.	Relative Azimuth Z (deg)	Range R (ft)	Average Density U_a (mW/cm^2)	Peak Power Density U_p (mW/cm^2)	Peak Electric Field Intensity E_p (V/m)
1	90	300	0.012	0.27	32
2	74	500	0.012	0.40	39
3	64	1000	0.014	0.30	34
4	60	1000	0.10	5.0	137

11 on Figure 4-1. The locations of these sites in terms of distance and sector are given in Table 4-2 together with calculated values of RFR.

The values presented in Table 4-2 are believed typical for locations in the vicinity of the proposed SEPP site. RFR values for other points of interest can readily be estimated by reference to the maps and the curves presented in Figures 4-2 and 4-3.

4.1.1.2 Human Health Effects

4.1.1.2.1 Background

4.1.1.2.1.1 Definition of RFR. In the sections on the effects of exposure to RFR on human health and on plants and animals, "RFR" is used as a generic term to include other terms commonly found in the bioeffects literature, such as electromagnetic radiation (EMR), nonionizing electromagnetic radiation (NIEMR), microwave radiation, radiofrequency electromagnetic (RFEM) fields, electromagnetic fields (EMF), microwave fields, and others. The frequency range of primary interest to the Air Force is from 10 kHz to 300 GHz. However, in this document, the term RFR applies to frequencies from 0 to 300 GHz, both unmodulated and modulated. The PAVE PAWS frequency band is 420 to 450 MHz.

4.1.1.2.1.2 The Problem. The basic issue addressed in this section on human health is whether brief or continual exposure of people to the power densities of RFR produced by SEPP is likely to affect their health adversely. A critical review of the present state of knowledge regarding biological effects of RFR has been prepared to serve as the primary reference for the human health aspects of this assessment of SEPP and of other proposed Air Force RFR-emitting systems. This review is Air Force School of Aerospace Medicine Report SAM-TR-83-1, entitled "Bioeffects of Radiofrequency Radiation: A Review Pertinent to Air Force Operations,"

Table 4-2

CALCULATED VALUES OF GROUND LEVEL RFR AT SELECTED LOCATIONS NEAR ROBINS AFB

	Sector	Site	Elevation	R	Elevation Angle	Az	Z	U_a	U_p	E_p
Luna Lake south shore	A_1	5	285	3,700	+0.15	10	60	0.014	1.8	82
Residence SW of radar	A_1	6	360	7,000	+0.70	230	40	0.0075	1.1	64
City Hall in Warner Robins	C	7	350	18,000	+0.24	320	87	0.000 003	0.000 75	1.7
Radio tower	A_1	8	450	9,800	+1.02	238	48	0.0048	0.80	55
Radar range	C	9	320	8,000	+0.32	310	87	0.000 016	0.0030	3.4
Avionics repair	C	10	280	9,500	+0.03	320	87	0.000 012	0.0024	3.0
Base housing	B	11	290	6,000	+0.14	356	74	0.000 08	0.014	7.3

U_p = Peak power density (mW/cm^2)
U_a = Average power density (mW/cm^2)
E_p = Peak electric field intensity (V/m)
R = Range (ft)
Az = Azimuth (deg)
Z = Relative azimuth (deg)

Radar base elevation = 275 ft
Radar face elevation = 330 ft
Boresight azimuths = 70 and 190 deg
Scan limit azimuths = 10 and 250 deg
Surveillance beam elevation angle = 3 deg
Surveillance duty cycle = 15%

by L. N. Heynick and P. Polson. It does not contain any system-specific information. The discussion and conclusions presented herein regarding possible RFR-bioeffects of SEPP were derived by considering the research results that are most significant scientifically and pertinent to the operational characteristics of SEPP and to the power densities of RFR in the geographic region outside the exclusion fence of the primary Robins AFB site.

Starting with Section 4.1.1.2.2, "Present Climate and Context," the RFR-bioeffects sections are organized in parallel with the corresponding sections of the review; the prefix 4.1.1.2 can be removed from these section numbers to obtain the corresponding section numbers in the review. Also, where appropriate, parts of the review are reproduced below with the bibliographic references removed and with other minor changes. This parallel arrangement is to permit use of this assessment as a complete document without having to refer to the review unless more details and the reference citations are desired.

Humans can be exposed to the RFR from SEPP under two circumstances. First, people airborne in the vicinity of SEPP may be exposed to the main beam and first sidelobe in addition to higher order sidelobes. Second, populations outside the exclusion area will be exposed more or less continuously to the low-intensity RFR existing near the ground for several miles from the radar. (Possible exposure of individuals within the exclusion area is excluded from consideration because the Site Command will provide appropriate protective and control measures.)

4.1.1.2.1.2.1 Airborne Exposure. Exposure of people in an airplane to the main beam is a possibility shared with many operational high-power radar systems. However, as far as is known, no case of harm to humans from any such incidental exposure has ever been reported, and there is no reason to believe that the SEPP situation would be significantly different from that of other radar installations in this respect.

Calculated average power densities in the surveillance volume of SEPP under worst-case conditions are about 3 mW/cm^2 at 1,850 ft from the radar (the approximate boundary between the near- and far-field regions) and about 0.4 mW/cm^2 at 1 mile. Within 1,850 ft, the average power density will not exceed about 57 mW/cm^2. Exposures of a few minutes at such average power densities are unlikely to be hazardous for airborne persons.

A phenomenon associated with RFR pulses per se is the perception of individual pulses as apparent sound. The threshold pulse power density for this effect (discussed in Section 4.1.1.2.6.5.1) is about 300 mW/cm^2. Calculated pulse power densities on the axis of the main beam of SEPP will be less than this value for distances exceeding about 3,200 ft. Thus, airborne persons in the main beam beyond this distance are not likely to "hear" the pulses. The pulse power density will be higher than 300 mW/cm^2 at distances smaller than 3,200 ft along the main-beam axis but will nowhere exceed about 900 mW/cm^2. Thus, airborne persons within this range may perceive the pulses. However, there

is no experimental evidence that persons would be adversely affected by exposure to such levels of pulse power density, at least for exposures of a few minutes. In addition, human volunteers have been exposed to pulse power densities as high as 2,000 mW/cm^2 (i.e., well above the 900 mW/cm^2 value) without ill effects.

Because of these considerations, possible exposures of persons in aircraft to the main beam of SEPP are not given further attention in the biological assessment for the primary site.

4.1.1.2.1.2.2 Near-Ground-Level Exposure. For SEPP, the calculated average power densities to which the general public (including civilian and military people on Robins AFB) may be chronically exposed are 0.014 mW/cm^2 at the Luna Lake south shore 3,700 ft from the radar, 0.008 mW/cm^2 at the residence 7,000 ft southwest from the radar, and less than 0.001 mW/cm^2 at a representative point in the Robins AFB base housing (6,000 ft), Robins AFB Radar Range (8,000 ft), Robins AFB avionics repair facilities (9,500 ft), and Warner Robins City Hall (18,000 ft). Members of the general public may be nonchronically exposed to higher average power densities if they approach the exclusion fence. In the beam overlap sector at 1,000 ft, the maximum ground-level average power density would be 0.1 mW/cm^2; at the two intersections of the exclusion and security fences 300 ft from the radar, which are the locations of closest possible public approach, the calculated value is 0.012 mW/cm^2. These values do not include attenuation due to the presence of foliage. At Robins AFB, the area outside the exclusion fence is heavily wooded, which would reduce the above values at least tenfold.

The highest values of pulse power density for individual pulses were calculated directly rather than inferred from mean duty cycles and again do not include attenuation from foliage. The values are 1.8 mW/cm^2 at the Luna Lake south shore, 1.1 mW/cm^2 at the residence 7,000 ft southwest from the radar, 0.014 mW/cm^2 at the base housing, 0.003 mW/cm^2 at the radar range, 0.0024 mW/cm^2 at the avionics repair facilities, and less than 0.001 mW/cm^2 at City Hall. At 1,000 ft in the beam-overlap sector, the value is 5.0 mW/cm^2, and at the intersections of the exclusion and security fences it is 0.27 mW/cm^2.

At the top of the radio tower 9,800 ft southwest of the radar, a location not readily accessible to the general public, the average power density is less than 0.005 mW/cm^2, and the pulse power density is 0.80 mW/cm^2.

4.1.1.2.1.3 Data Base and Literature Selection. The criteria used in selecting articles for inclusion in the bioeffects review are described therein.

4.1.1.2.1.4 Eastern European Bioeffects Literature. Probably the most controversial aspects of research on the biological effects of RFR are the large discrepancies between results, at low levels of RFR, reported in the Eastern European literature and those obtained in Western countries such as the United States, and the basic differences in philosophy

between the two groups of countries in prescribing safety standards or guidelines for the protection of humans against possible hazards from exposure to RFR.

From the end of World War II to about the late 1960s, few of the scientific reports on bioeffects research in the USSR (or other Eastern European countries) were amenable to critical review because they lacked essential information. In the early 1970s, starting essentially with an international conference on the bioeffects of RFR in Warsaw in 1973 under the joint sponsorship of the World Health Organization (WHO), the U.S. Department of Health, Education, and Welfare (HEW), and the Scientific Council to the Minister of Health and Social Welfare of Poland, international interchanges of information increased materially, and translations of Eastern European articles became easier to obtain. Because most Eastern European documents published before 1973 (and many since then) are merely abstracts that contain no details of the experimental method, number of subjects, or analytical approach used in the study, evaluating them was difficult. More recent Eastern European studies contain more detail, and some of them have been cited and analyzed in the review.

4.1.1.2.2 Present Climate and Context

4.1.1.2.2.1 Proliferation of RFR Emitters. Public use of RFR-generating devices and acceptance of their benefits have been growing almost exponentially over a number of years. Public television and radio broadcasting stations, ham radio transmitters, citizen band radios, ground-level and satellite communication systems, civil and military aircraft navigation systems, airport traffic control systems, medical diathermy units, defense tracking systems, remote garage-door opening devices, microwave ovens, and a variety of units for industrial heating and processing of materials contribute to the expansion of RFR use in this country.

All of these devices are regulated by the federal government, mainly the Federal Communications Commission (FCC), and all are restricted to specific frequency bands. The power levels that most devices may emit are also restricted. Still, as the number of such devices increases, the background level of RFR in this country, particularly in urban and industrial centers, is bound to increase as well. It is therefore appropriate to ask whether this increasing level of RFR will be deleterious to human health.

Various agencies of the federal government have established programs to deal with the question of effects of RFR on human health. The U.S. Air Force has taken an active role for more than 10 years to advance the state of knowledge of RFR bioeffects in the interest of personnel safety. The Environmental Protection Agency (EPA) is conducting a study of environmental levels of RFR. The Bureau of Radiological Health (BRH) has promulgated a performance standard for permissible microwave oven leakage (21 CFR 1010, "Performance Standards for Electronic Products"). The National Institute for Occupational Safety and Health (NIOSH) is investigating the use of industrial microwave devices. The Air Force, together with the Army, Navy, and other government agencies, maintains

research programs on the biological effects of RFR, with the objective of assessing effects on human health. The results of these programs indicate that the biological effects of RFR are largely confined to average power densities exceeding about 1 mW/cm^2.

In summary, the benefits of RFR devices for communications, radar, personal and home use, and industrial processes are widely accepted. On the other hand, many are concerned that the proliferation of the use of RFR devices, including various military radar and communications systems, may be associated with some as-yet-undefined hazardous biological effects. The purpose of this document is to address such concerns as they pertain to SEPP.

4.1.1.2.2.2 Measurements of Environmental Levels of RFR in Selected U.S. Cities. EPA has measured the environmental field intensities at selected locations in various U.S. cities. Recent reports discuss the results for the 15 cities (a total of 486 sites) studied so far. The sites in each city were selected to permit estimations of cumulative fractions of the total population being exposed at or below various average power densities, based on the population figures for the 1970 census enumeration districts.

The measured field strengths at each site were integrated over the frequency bands from 54 to 890 MHz included in the analyses and converted into equivalent average power densities. The site values in each city were then used with the population figures in the various census enumeration districts in a statistical model designed to estimate the population-weighted median exposure value for that city and to calculate other statistics of interest. These median values range from 0.000002 mW/cm^2 (for Chicago and San Francisco) to 0.000020 mW/cm^2 (for Portland, Oregon). The population-weighted median for all 15 cities is 0.0000048 mW/cm^2. Also, the percentage of the population of each city exposed to less than 0.001 mW/cm^2 ranges from 97.2% (for Washington, D.C.) to 99.99% (for Houston, Texas), with a mean value for all 15 cities of 99.4%. The major contributions to these exposure values are from the FM-radio and TV broadcast stations.

EPA also measured RFR levels at sites close to single or multiple RFR emitters, e.g., at the bases of transmitter towers and at the upper stories (including the roof) of tall buildings or hospital complexes close to transmitter towers. At the base of an FM tower on Mt. Wilson, California, for example, the fields ranged from 1 to 7 mW/cm^2, but such values are believed to be uncommon. Most measurements in tall buildings close to FM and TV transmitters yielded values well below 0.01 mW/cm^2, but a few values were close to or slightly exceeded 0.2 mW/cm^2 (e.g., 0.23 mW/cm^2 on the roof of the Sears Building, Chicago).

4.1.1.2.2.3 Problems of Risk Assessment. Assessing risk to human health and setting standards to protect health are extremely complex problems. In addition to purely technical and scientific questions, there are problems, still only vaguely recognized, of philosophy, law, administration,

and feasibility of programs. Although dealing with those subjects in detail is beyond the scope of this document, it is important that they be mentioned.

One distinction between RFR and ionizing radiation is the considerable experimental evidence for the existence of exposure thresholds for various RFR effects. In the RFR-bioeffects review, threshold levels are considered on a case-by-case basis, with due regard for the physiological mechanisms of effect.

4.1.1.2.2.4 Exposure Standards. The term "exposure standards" is generally applied to specifications or guidelines for permissible occupational and/or nonoccupational exposure of humans to electromagnetic fields. The standards are expressed as maximum power densities or field intensities in specific frequency ranges and for indicated exposure durations.

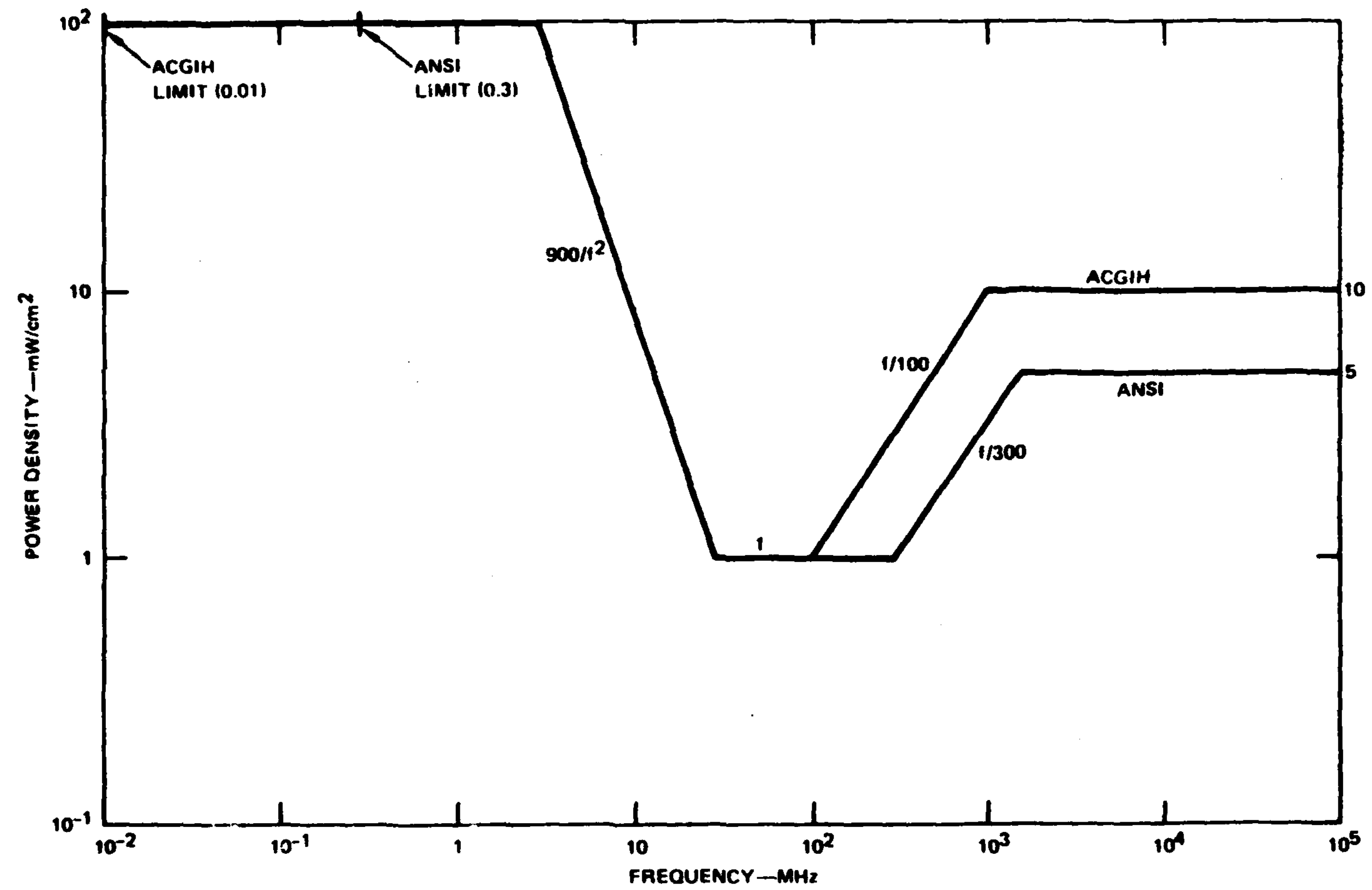
The American National Standards Institute (ANSI) Subcommittee C95.4 has adopted a frequency-dependent standard for both occupational and general-public exposure to RFR, to replace the ANSI Radiation Protection Guide, published in 1974, of 10 mW/cm^2. The new ANSI standard, shown in Table 4-3 and graphically in Figure 4-5, was derived from analyses of many representative recent experimental and theoretical results selected by a subcommittee of ANSI C95.4. It covers the frequency range from 300 kHz to 100 GHz and is based on a mean whole-body specific-absorption-rate (SAR) limit of 0.4 W/kg instead of a constant incident power density. SAR is defined as the rate at which radiofrequency electromagnetic energy is imparted to an element of mass of a biological body (see Section 4.1.1.2.5.1.2 for a more detailed discussion of SAR). The lowest limit, 1 mW/cm^2, is for the range from 30 to 300 MHz, within which RFR absorption by the human body as a resonant entity is highest. The value 0.4 W/kg includes a safety factor of 10, and the specified limits are not to be exceeded for exposures averaged over any 0.1-hr period.

Table 4-3

NEW ANSI RADIOFREQUENCY RADIATION PROTECTION GUIDES

(1) Frequency Range (MHz)	(2) E^2 (V^2/m^2)	(3) H^2 (A^2/m^2)	(4) Power Density (mW/cm^2)
0.3 - 3	400,000	2.5	100
3 - 30	4,000 ($900/f^2$)	0.25 ($900/f^2$)	$900/f^2$
30 - 300	4,000	0.025	1.0
300 - 1500	4,000 (f/300)	0.025 (f/300)	f/300
1,500 - 100,000	20,000	0.125	5.0

Note: f is the frequency in MHz.



*Based on average SAR limit of 0.40 W/kg in exposed tissue.

FIGURE 4-5 ANSI AND ACGIH SAFETY GUIDES FOR WHOLE-BODY EXPOSURE OF HUMANS*

In the far field of an RFR source, the governing maximum values are the power densities shown in column 4 of Table 4-3, and the corresponding squares of the electric- and magnetic-field amplitudes (E^2 and H^2) in columns 2 and 3 are approximate "free-space" equivalents.

In the near field of an RFR source, the governing maxima are the values of E^2 and H^2 but can be expressed in terms of corresponding power densities as is done in Figure 4-5.

The ANSI power density limits for the PAVE PAWS 420- to 450-MHz range are 1.4 to 1.5 mW/cm^2.

The American Conference of Governmental Industrial Hygienists (ACGIH) has proposed (in a notice of intent) a new standard also based on 0.4 W/kg, but for occupational exposures only. The ACGIH threshold limit values are displayed graphically in Figure 4-5 for comparison with the ANSI values. The major difference is that the 1 mW/cm^2 value extends only from 30 to 100 MHz and rises from the latter with a slope f/100 to 10 mW/cm^2 at 1 GHz. This difference is based on the premise that children, who have higher whole-body resonant frequencies than adults (see Section 4.1.1.2.5.1.2), are not likely to be occupationally exposed to RFR. Another difference is that the lower frequency limit for the ACGIH standard is at 10 kHz instead of 300 kHz.

The currently applicable Air Force permissible exposure limits (PELs) are given in AFOSH Standard 161-9. For exposures averaged over any 0.1-hr period to frequencies between 10 MHz and 300 GHz, the PEL is 10 mW/cm^2, and from 10 MHz down to 10 kHz, the PEL is 50 mW/cm^2. For exposure within any 0.1-hr period, the product of the power density and the exposure duration shall not exceed 3,600 mW-s/cm^2 for frequencies between 10 MHz and 300 GHz, or 18,000 mW-s/cm^2 for frequencies between 10 kHz and 10 MHz. This standard is being revised: Currently proposed PELs for exposure, during any 0.1-hr period, of adults of normal size (55 in. or more in height) are the new ACGIH values, and the PELs for exposure of humans of small size (less than 55 in. tall) are the new ANSI values, but extended down to the ACGIH lower frequency limit of 10 kHz. For the 420- to 450-MHz range, the new PELs are 4.2-4.5 mW/cm^2 for humans of normal size and 1.4-1.5 mW/cm^2 for humans of small size.

An exposure standard for the general (nonoccupational) population is also under consideration by the EPA.

For general interest, the standards of Canada and Sweden and the standards adopted or proposed by several state, county, and municipal governments in the United States are discussed in the RFR-bioeffects review.

Exposure limits in the USSR are considerably lower than those of Western countries, especially the limits for general population exposure. We surmise that such standards are based on the philosophy that exposure to power density levels that cause relatively small changes from normal mean values is potentially harmful. Until recently, the maximum level

for 24-hr exposure of the general population was 0.005 mW/cm^2, and the occupational standard was as summarized in Table 4-4. This table specifies higher maximum levels than those for the general population. For example, for rotating antennas emitting in the 420- to 450-MHz range, it permits exposures to 0.1 mW/cm^2 for a full working day or 1 mW/cm^2 for 2 hr. (Phased-array antennas such as those of PAVE PAWS are analogous to rotating antennas.) The Soviet military services and establishments were specifically exempted from such standards.

Recent U.S. visitors to the USSR have reported pending and/or adopted revisions to the standards above (Microwave News, November 1982.) For 24-hr exposure of the general population, the maximum level has been increased from 0.005 to 0.010 mW/cm^2. Also, the USSR appears to be developing standards for specific types of RFR emitters. As examples, for a specific radar that emits 1-microsecond pulses of 10-cm (3-GHz) RFR at 3 pps, the exposure limit is 0.015 mW/cm^2 (average power density), and for microwave ovens, the maximum value at the distance of 50 cm is 0.010 mW/cm^2. Regarding occupational exposure, for the frequency range from 0.3 to 30 GHz and exposures of 0.2 hr or longer, the product of the average power density and the exposure duration should not exceed 0.2 $mW\text{-}hr/cm^2$. Thus, the exposure limit for an 8-hr working day has been increased from 0.010 to 0.025 mW/cm^2, the limit for 2-hr exposure is 0.1 mW/cm^2 (no change), and the 1 mW/cm^2 limit is for

Table 4-4

USSR MAXIMUM PERMISSIBLE LEVELS FOR OCCUPATIONAL EXPOSURE

Frequency (GHz)	Exposure Duration	Exposure Limit	Remarks
0.01 to 0.03	Working day	20 V/m	--
0.03 to 0.05	Working day	10 V/m 0.3 A/m	--
0.05 to 0.3	Working day	5 V/m 0.15 A/m	--
0.3 to 300	Working day	0.01 mW/cm^2	Stationary antennas
	Working day	0.1 mW/cm^2	Rotating antennas
	2 hr	0.1 mW/cm^2	Stationary antennas
	2 hr	1 mW/cm^2	Rotating antennas
	20 min	1 mW/cm^2	Stationary antennas

exposures of less than 12 (instead of 20) min. Though not stated, by implication these changes are applicable to RFR from stationary antennas; no information regarding rotating antennas was obtained. The limits for the frequency ranges 0.03 to 0.05 GHz and 0.05 to 0.3 GHz are unchanged.

The exposure limits in Poland and Czechoslovakia are higher than those of the USSR but lower than those of the Western countries.

If the attenuation due to foliage is included, the average power densities from SEPP for chronic exposure of the general public are smaller than the new USSR safety standard of 0.010 mW/cm^2 for continuous (24-hr) exposure of the general population. Thus, the controversy regarding the large differences in the United States and USSR standards is not really relevant to the issue of whether the RFR from SEPP is hazardous to human health.

4.1.1.2.3 Assessment of Scientific Information. In an assessment of the potential biological effects of RFR from a specific system, it is necessary to consider certain quantitative relationships among (1) the physical parameters of the RFR such as frequency, power density, and polarization; (2) the mechanisms of absorption and distribution of energy within the biological organism; and (3) the resulting biological effects as measured by some functional or anatomic alteration. Like all scientific theory, the body of biophysical theory that links these three factors has been synthesized from a variety of experimental evidence. The theory is subject to refinement or revision as valid new evidence accumulates that is inconsistent with the theory. Nevertheless, it furnishes the context in which new experimental evidence is considered.

The most directly applicable experimental evidence concerning possible bioeffects of any specific system would come from experiments in which humans were exposed to its specific frequency range and likely power density values. Furthermore, the best evidence would come from quantitative evaluation of a large number of biological endpoints. Such data, however, do not exist. The relatively small amount of data on human exposure to RFR was derived primarily from epidemiologic studies conducted after exposure. Such studies are rarely adequate because the numerical values of the exposure parameters for most epidemiologic studies are not known in detail, and the unexposed control group of people selected for comparison may differ significantly from the exposed population in factors other than exposure to RFR. Most available information is indirect because it is derived primarily from experiments with animals and requires at least some extrapolation of species, field characteristics, duration of exposure, and biological effects.

Regardless of the particular line of evidence being considered, certain concepts and constraints affect the interpretation. In particular, scientists disagree over whether an effect, especially one that is reversible or compensable, constitutes a hazard. Furthermore, only rarely is any particular study subjected to confirmation by the performance of an identical experiment by another investigator. More often, an analogous--but not identical--experiment is conducted with the

objective of clarifying or expanding the results of the initial experiment. The second experiment ideally provides a better means of incorporating the findings into the theory that underlies the body of knowledge in a particular field of investigation, but it does not necessarily confirm the results of the first investigation.

Still another consideration is also important: scientific findings are probabilistic in nature, in that facts are known only to some level of probability for a given population; the applicability of those facts to a particular individual may be constrained. For example, the term "median effective dose" for a certain agent refers to the dose that will elicit the response characteristic of that agent in one-half of the exposed individuals. Before the dose is administered, however, one cannot predict whether any specific individual will respond, although the prediction that an individual will have a 50% chance of showing the response is valid. In effect, the probabilistic nature of scientific evidence means that no amount of scientific data can guarantee the absolute safety of any agent for any individual or group of individuals. Analysts disagree over whether the conventional scientific approach, whereby an investigator finds or fails to find a statistically significant (very low probability of chance occurrence) difference between experimental and control groups, is appropriate to considering potential hazards to humans. The scientist's statement that no statistically significant differences between the groups are discernible is not equivalent to the absolute statement that there is no difference between the groups.

Conceivably, agents may have effects that are biologically real but so small in magnitude that the difference in mean response between experimental and control populations may not be discernible within the scattering of values for both populations if the sample sizes are small. Biological studies to detect such small differences and to show that they are statistically significant (to a prespecified probability that they are not due to chance) would require the use of large numbers of animals and, in some cases, long exposure times. The expenditures in time and money necessary to perform such studies may be so large that sponsoring institutions with limited budgets often decide that such studies are not cost-effective in terms of the sponsor's overall objectives. A frequent alternative is to predict effects at very low levels by extrapolation from findings at higher levels, on the basis of assumptions about the mathematical relationship between the level (or dose) of the agent and the degree of the effect. Such assumptions are open to challenge, however, and this approach may lead to disagreement over the possible existence of a threshold dose or dose rate below which the agent has no effects.

It must also be remembered that scientists have personal values, goals, and attitudes. It has been said that there is no such thing as an unbiased expert because becoming an accepted authority involves a personal commitment over a period of time that leads to emphasis of certain viewpoints. Thus, like probabilistic scientific findings, objectivity may well be characteristic of scientists as a group without necessarily

being characteristic of any individual scientist. Personal bias can consciously or unconsciously affect how the experiment is designed, how the data are interpreted, and particularly, how the results are applied to decision making. The last is especially important when the decision to be made is in an area outside the scientist's field of expertise.

Finally, scientific experiments are usually restricted to the evaluation of only one factor. In the real world, however, interactions are far more complex. The effect of combinations of factors is illustrated in the incidence of lung cancer in uranium miners, which is higher than in the general population, presumably as a result of the inhalation of radioactive material. The extent of the increased incidence in nonsmoking miners is marginal, but miners who smoke cigarettes have a much higher incidence of lung cancer than either nonsmoking miners or the general population. Thus, scientific evidence can only supply probabilistic information that is relatively narrow in its application to the real world.

4.1.1.2.4 Other Assessments and Reviews. The Assembly of Life Sciences of the National Academy of Sciences (NAS) appointed the Panel on the Extent of Radiation from the first PAVE PAWS radar system (at Otis ANG Base, Massachusetts) to examine the levels of RFR to which the public may be exposed. In April 1979, the Panel released its report, entitled "Analysis of the Exposure Levels and Potential Biologic Effects of the PAVE PAWS Radar System." The report covered the RFR levels to which the general population may be exposed from that radar, the various biological effects of RFR in animals, and the reported effects of RFR in humans. The distinction between an effect and a hazard was made, and the difficulties of risk assessment were discussed, including the lack of adequate epidemiologic studies. For discussing the biological effects of RFR, an average power density of 1 mW/cm^2 was selected as the arbitrary boundary between "high-intensity" and "low-intensity" effects. The authors cited 170 references, concluding that exposure of humans to low-intensity RFR can have effects, but that on the basis of (then) current information, the known or suspected effects are reversible and not associated with increased morbidity or mortality. The specific conclusion with regard to that PAVE PAWS is quoted below.

> In conclusion, the PAVE PAWS radar may be anticipated to expose a limited number of members of the general public intermittently to low intensities of pulse-modulated microwave fields with maximal instantaneous intensities of 0.1 mW/cm^2 or less and time-averaged intensities lower by two orders of magnitude. There are no known irreversible effects of such exposure on either morbidity or mortality in humans or other species. Thus, it is improbable that exposure will present any hazard to the public. In view of the known sensitivity of the mammalian CNS to electromagnetic fields, especially those modulated at brainwave frequencies, the possibility cannot be ruled out that exposure to PAVE PAWS radiation may have some effects on exposed people. Because these effects are still hypothetical, it is not feasible to assess their health

implications. Such assessment will require additional research and surveillance and must be addressed in future evaluations of the potential exposure effects of PAVE PAWS and other high-power-output radar systems.

Representative, more general reviews of the literature on RFR bioeffects, including several papers by Eastern European authors, are described in Section 1.2 of the RFR-bioeffects review, primarily as background material. Although the conclusions of the authors of those reviews and of the NAS assessment were examined carefully, it is important to note that the conclusions presented below regarding the consequences of human exposure to the RFR from SEPP were derived independently.

4.1.1.2.5 Present State of Knowledge Regarding Physical Effects

4.1.1.2.5.1 Interactions of RFR with Biological Entities. Interactions of electromagnetic fields with biological entities are often loosely characterized in the bioeffects literature as "thermal" or "nonthermal," a usage that has led to confusion and controversy. Therefore, it is appropriate at this point to introduce working definitions of these terms, with the recognition that the boundary between these types of interaction is not sharp.

The interaction of an agent (e.g., RFR) with an entity (biological or nonbiological) can be characterized as thermal if the energy absorbed by the entity is transformed at the absorption site into heat. Heat absorption, in turn, is defined in classical thermodynamics as either an increase in the mean random speed (or kinetic energy) of the molecules at the site (a local increase in temperature), or as an increase in the disorder or randomness of the molecular motion without an increase in mean random speed (a first-order phase change, such as the process involved in ice melting at 0 deg C), or both.

An entity can also absorb energy at specific discrete frequencies in the form of energy packets or quanta, each of which has an energy proportional to one of the discrete frequencies. Although large numbers of molecules can be involved, quantum absorption is essentially a microscopic phenomenon in that the constituents and configurations of the various molecular species comprising the entity determine the specific frequencies or characteristic spectra at which such absorption can occur. The kinds of interactions involved are numerous and of varying degrees of complexity. They include alterations of molecular orientations and configurations that do not change the basic identities of the molecules, disruption of intermolecular or intramolecular bonds, and excitation of atoms or molecules to higher electron states (including ionization). Such interactions can be characterized as "short-range" processes.

It is theorized that cooperative interactions also occur among subunits of molecules within biological cells, in cell membranes, and in extracellular fluids. Cooperative interactions are often characterized

as "long-range" because absorption of energy at one specific site in a structure (e.g., in a membrane or in a biological macromolecule) can affect a process elsewhere in the structure, or a function of the structure as a whole can be triggered by the release of energy stored in the structure, thereby producing biological amplification.

Conceptually, all such quantum interactions can be characterized as "nonthermal." However, if most of the energy thus absorbed is subsequently transformed locally into heat (as defined above), the distinction between nonthermal and thermal is blurred. Pragmatically, therefore, characterization of an interaction of RFR with a biological entity as nonthermal requires that the interaction give rise to a frequency-specific effect that is experimentally distinguishable from heating effects caused by thermalization of the absorbed RFR energy.

4.1.1.2.5.1.1 Thermal Interactions. Consider now the effects of CW RFR on a human or an animal. The relative magnetic permeability of most organic constituents is about unity. Therefore, thermal interactions (as defined above) can be described in terms of the dielectric, electrically conductive, and thermal properties of the body organs, tissues, fluids, and so forth, as well as the characteristics of the RFR (frequency, power density, polarization). Measurements of these properties have been made for various mammalian tissues, blood, cellular suspensions, protein molecules, and bacteria over the frequency range from about 10 Hz to 20 GHz. In the subrange from about 300 MHz to about 10 GHz, the dielectric constant of such constituents as skin, muscle, and blood vary little with frequency; the differences in values among such constituents are largely due to differences in water content. In addition, electrical conductivity increases slowly with frequency in this subrange.

Because the index of refraction of any material is related to its dielectric constant, RFR is reflected and refracted at boundaries between regions of differing dielectric properties, such as at the surface of a body (whether organic or inorganic), for the same physical reasons as for light at a glass-air interface. Thus, RFR at normal incidence to a relatively thick planar specimen is partially reflected at the surface, and the fraction of the power density entering the specimen suffers progressive attenuation with depth because of energy absorption. The concept of "penetration depth" is often used. For homogeneous specimens, the penetration depth is defined as the distance at which the electric-field strength is about 37% of its value or the power density is about 14% of its value just within the surface, and the numerical values depend on the electrical properties of the material. Both the reflection ratio and penetration depth vary inversely with frequency. At 450 MHz, about 65% of the incident power density is reflected at the air-skin interface, and the penetration depths for skin, muscle, and blood are about 3 cm (1.2 in.) and about sixfold larger for fat. Therefore, the 35% entering the body passes through the skin and its underlying fat layer into the muscular tissue with relatively little attenuation. At 100 kHz, the penetration depths of all constitutents are quite large, but the reflection ratio is essentially 1. On the other hand, at approximately 10 GHz and higher, a somewhat smaller

fraction of the incident power density than at 450 MHz is reflected, but penetration is largely confined to the skin.

4.1.1.2.5.1.2 Dose-Rate Considerations. In the literature on bio-effects of RFR, thermal energy absorption from an electromagnetic field is usually characterized by the specific absorption rate (SAR), which is defined as the rate of energy absorption per unit volume in a small volume at any locale within an entity, divided by the mean density of the constituents in that volume. SAR is expressed in terms of W/kg or mW/g (1 mW/g = 1 W/kg). The numerical value of SAR in any small region within a biological entity depends on the characteristics of the incident field (power density, frequency, polarization), as well as on the properties of the entity and the location of the region. For biological entities that have complex shapes and internal distributions of constituents, spatial distributions of local SAR are difficult to determine by experiment or by calculation. Thus, the concept of "whole-body SAR," which represents the spatial average value for the body per unit of incident power density, is useful because it is a quantity that can be measured experimentally--e.g., by calorimetry--without information on the internal SAR distribution.

Many investigators have calculated or measured SAR for relatively simple geometric models, including homogeneous and multilayered spheroids, ellipsoids, and cylinders that have weights and dimensions approximately representative of various species, including humans. An important result of this work is that the largest value of whole-body SAR is obtained when the longest dimension of each kind of model is parallel to the electric component of a linearly polarized plane-wave field and when the wavelength of the incident RFR is about 2.5 times the longest dimension. The adjective "resonant" is often applied to the frequency corresponding to this wavelength. The resonant value of whole-body SAR for each model is also inversely dependent on the dimension perpendicular to the polarization direction (and propagation direction) of the field; i.e., the model has characteristics somewhat similar to those of a lossy dipole antenna in free space. Resonances would also occur for circularly polarized RFR (the type of polarization used in PAVE PAWS). Such RFR can be resolved into two mutually perpendicular components, each having half the total power density. Therefore, an entity exposed to circularly polarized RFR would have lower resonant SAR values than it would have if exposed to linearly polarized RFR of the same total power density.

Based on prolate-spheroidal models (and linearly polarized RFR), the resonant frequency for an "average" man, approximately 5 ft 9 in. tall (1.75 m) and weighing about 154 lb (70 kg) is about 70 MHz; at this frequency the mean SAR is about 0.2 W/kg for 1 mW/cm^2 incident power density, or about 1/6 of his resting metabolic rate, or about 1/21 to 1/90 of his metabolic rate when performing exercise ranging from walking to sprinting. An alternative interpretation of this mean SAR value is that exposure to 1 mW/cm^2 for, say, 1 hr would produce a mean temperature rise of about 0.2 deg C in the absence of any heat-removal mechanisms. However, actual temperature increases would be lower or even

zero because physical heat-exchange mechanisms (conduction, convection, radiation) are always present, and for mammals (and other warm-blooded species) these mechanisms are controlled by thermoregulatory systems.

Similarly, the resonant frequency for an "average" woman about 5 ft 3 in. tall is about 80 MHz, and her mean SAR is about the same as for the average man. The resonant frequency of a 10-year-old is about 95 MHz; for a 5-year-old, about 110 MHz; and for a 1-year-old, about 190 MHz. The mean resonant SAR values for such children are about 0.3 W/kg for 1 mW/cm^2.

If a model human were to be standing on a wet surface or near other electrically conductive surfaces (reflectors), the resonant frequency would be lower and the mean SAR (at the lower resonant frequency) would be higher. However, because the values of incident power density from SEPP at ground level beyond the exclusion area are much lower than 1 mW/cm^2 and its operational frequencies are considerably higher than the resonant frequencies in either the absence or presence of nearby reflecting surfaces, no changes in body temperature would be expected.

The foregoing discussion of mean SAR also largely applies to pulsed RFR (and other types of modulated RFR) at corresponding carrier frequencies and time-averaged incident power densities. (However, as discussed in the next section, interactions of CW- and pulsed RFR with biological entities differ in several ways.)

An early, very significant finding for spherical models of the isolated head assumed to be exposed to plane-wave RFR was the discovery of local regions of relative maximum SAR values. The locations of such regions depend on the size of the head, the electromagnetic characteristics of its layers, and the wavelength of the incident field. These regions have been conveniently dubbed "hot spots," even for combinations of incident power density and exposure duration that would produce biologically insignificant temperature increases at such spots. Pertinent hot-spot data are given in the RFR-bioeffects review.

Results of theoretical analyses of SARs have been verified experimentally. Physical models of simple geometry or in human- or animal-figurine shape were constructed from synthetic biological materials that have approximately the same electromagnetic characteristics as their corresponding biological constituents; the models were then exposed to sufficient power densities to obtain readily measurable temperature increases, which were measured immediately after irradiation.

Among the qualitative results of general interest obtained with human figurines are that, at frequencies near resonance, the local fields can be much higher for certain regions such as the neck and groin than for other body locations, and that field distributions for nonprimates differ greatly from those for primates. The latter point should be given proper consideration when one endeavors to extrapolate experimental bioeffects findings on any laboratory animal species to humans or to compare experimental results on one laboratory species with those on another

species. However, the PAVE PAWS frequencies are much higher than the human resonance values (e.g., 70 MHz for the model average man) and the corresponding mean SAR values (per mW/cm^2) are considerably lower than the resonance values (e.g., about 0.026 W/kg at 450 MHz versus 0.2 W/kg at 70 MHz). Consequently, local temperature rises in body regions such as the neck and groin would be negligible for the power densities beyond the exclusion area.

4.1.1.2.5.1.3 Quantum Interactions and Nonthermal Effects. For short-range quantum interactions (as defined in Section 4.1.1.2.5.1) of CW RFR, the discrete frequencies are in the infrared range from about 19,000 to 2,400,000 GHz, and the lower end of this range is about 42,000 times higher than a quantum of RFR at 450 MHz. Conversely, the quantum energy of 450-MHz radiation is too low (by a factor of 50,000 or more) for such interactions. Therefore, the existence of nonthermal biological effects of CW RFR ascribable to such short-range molecular interaction mechanisms is extremely doubtful.

It has been logically postulated that cooperative or long-range quantum processes in biological entities (or the functions resulting therefrom) could be altered by exposure of the entity to external fields of magnitudes that do not produce heat as the primary or initial product. Much research has been done with models of cellular membranes. In general, the results indicate that cooperative processes have activation energies or exhibit resonant frequencies that can be much lower than those for short-range interactions.

The mean thermal energy corresponding to the physiological temperature 98.6 deg F (37 deg C) is about 0.027 eV, with a classical spectral distribution around a maximum at 6,500 GHz and encompassing the frequency range for cooperative processes. Therefore, as a counter-argument to the manifestation of such nonthermal effects, a question has been raised whether these effects would be distinguishable from those that are spontaneously induced thermally *in vivo*. Alternatively, separation of such RFR interactions from those thermally induced may require that the rates of occurrence of the former exceed the rates for the latter. This requirement implies that for manifestation of such effects of RFR, the intensity of the incident field must exceed minimum values or thresholds related to the specific processes.

Because predictions from various theoretical models and related considerations conflict to a significant extent, the issue of whether weak external fields at frequencies well below the infrared range (i.e., RFR) can alter biological processes is not yet resolved. However, increases and decreases of calcium-ion binding to cell membranes due to weak external RFR, a phenomenon called "calcium efflux," has been ascribed to alterations of cooperative processes by such fields. This phenomenon is discussed in Section 4.1.1.2.6.5.2.

4.1.1.2.5.1.4 Interactions of Modulated RFR. Precise usage of the term CW RFR implies the presence of only a single frequency (and unvarying incident power density). Because of the time variations of power density

and/or frequency in modulated RFR, possible biological effects ascribable to the modulation characteristics per se rather than to the time-averaged power density must also be considered, such as the calcium-efflux phenomenon, which was reported for 50-MHz, 147-MHz, and 450-MHz RFR modulated at sub-ELF frequencies but not for unmodulated RFR at these carrier frequencies.

Periodically pulsed RFR constitutes a particular type of amplitude-modulated RFR in which the pulse repetition rates are the primary modulation frequencies. Biological effects ascribable to modulation frequencies per se (as distinguished from those due to individual pulses) have been postulated. The calcium-efflux results are relevant to PAVE PAWS (especially those with modulated 450 MHz) because the pulse repetition rates of PAVE PAWS are approximately the same as the modulation frequencies used in those experiments.

4.1.1.2.5.1.5 Interactions of RFR Pulses. The interactions of individual RFR pulses with an entity (biological or nonbiological) are analogous to those of mechanical impulses, an impulse being defined as the sudden application of a force to an entity for a brief time interval, resulting in an abrupt increase in momentum. The total energy imparted to the entity depends on the magnitude of the force and the duration of its application. The interaction can be characterized as nonthermal or thermal, depending on the properties of the entity that determine the disposition of the energy. The impact of a piano hammer on a string, which excites the string into vibration at its discrete resonant frequencies (the fundamental frequency and integer-multiples thereof or harmonics), is an example of an essentially nonthermal interaction as defined previously; most of the energy is transformed into sound, which is converted into heat elsewhere.

A sudden blow to an entity such as a block of material having a set of resonant frequencies that are not necessarily harmonically related to one another will excite many of these frequencies; this illustrates the principle that an impulse contains a broad spectrum of frequencies. The results of an impact on a church bell can be characterized as nonthermal for the same reason as that given for the piano string. By contrast, the effects of a blow to a block of lead or asphalt are essentially thermal; even though some sound is produced, most of the energy is converted into heat on the surface of impact.

The temperature increase of any given region within a biological entity due to the arrival of a single RFR pulse would be small, because of the relatively large thermal time constants of biological materials and the operation of heat-exchange mechanisms. However, if the region contains a boundary between layers of widely different dielectric properties, then the temperature gradient (rate of temperature change with distance) can be large at such a boundary even though the mean temperature increase in the region is small.

One single-pulse effect known to occur in humans is the phenomenon of "microwave hearing" discussed in Section 4.1.1.2.6.5.1, or the

perception of single or repetitive short pulses of RFR as apparently audible clicks. The interaction mechanisms involved are not yet completely understood. However, most of the experimental results tend to support the theory that pulse perception occurs because the electromagnetic energy is transduced into sound pressure waves in the head at a boundary between layers having widely different dielectric properties (e.g., at the boundary between the skull and the skin or the cerebrospinal fluid). The energy in a pulse arriving at such a boundary is converted into an abrupt increase in momentum that is locally thermalized, producing a negligible volumetric temperature increase but a large temperature gradient across the boundary. Under such conditions, rapid local differential expansion would occur and create a pressure (sound) wave that is detected by the auditory apparatus. This effect is often characterized as nonthermal because the power density averaged over two or more pulses can be minuscule. Specifically, the time-averaged power density for two successive pulses is inversely proportional to the time interval between the arrival of the pulses at the perceiver, and this interval can be indefinitely long without affecting the perception of each pulse. Therefore, the time-averaged power density has no relevance to perception. Irrespective of how the RFR-hearing phenomenon is characterized, the significant point is that the preponderance of experimental evidence indicates that the pulses are converted into actual sound in the head, rather than perceived by direct RFR stimulation of the auditory nerves or the brain.

As discussed in Sections 4.1.1.2.6.5.3 and 4.1.1.2.6.6, pulsed RFR has been reported to produce other effects, such as alterations of the blood-brain barrier and behavioral changes.

4.1.1.2.5.2 Exposure Systems and Instrumentation for RFR Bioeffects Research. Much of the early laboratory research on RFR bioeffects suffered from lack of adequate systems for exposing the biological entities under study and lack of accurate techniques and instrumentation for measuring incident fields and/or determining energy absorption rates within such entities. The environmental characteristics of the exposure systems were often inadequately characterized or controlled. In addition, the instrumentation was frequently incorrectly used, or was the source of significant errors in numerical values or of spurious biological findings (artifacts) traceable to perturbations introduced by the presence of the sensors. For these reasons, many of the early results should be viewed as questionable, at least from a quantitative standpoint. During recent years, however, major advances have been made in specialized exposure systems and in instrumentation for determining incident-field intensities for biological research and for determining energy-absorption rates within biological entities. These developments are discussed in Sections 5.2.1 and 5.2.2 of the RFR-bioeffects review.

4.1.1.2.6 Present State of Knowledge Regarding Biological Effects

4.1.1.2.6.1 Epidemiology. Epidemiology, as used in the context of this document, refers to studies of whether one or more health-related conditions can be associated statistically with purported or actual exposure

of humans to RFR (in contrast with assessments based on extrapolation from data on animals to humans). Epidemiologic results tend to be based on imprecise estimates of exposure characteristics (frequency, power density, and duration). The extent to which the control group matches the exposed group is sometimes open to question. Because matching of all relevant factors except exposure is the basis for concluding that any observed differences between groups are related to the RFR exposure, selection of an appropriate control group is critical. Despite these limitations, such studies do provide almost the only information available on possible effects of actual RFR exposure in humans.

A group of reports was selected for review from the literature in the United States, Poland, Czechoslovakia, and the USSR. These reports provide a representative sample of the kinds of information currently available.

The U.S. Embassy in Moscow was subjected to RFR from 1953, the year after the United States moved its chancery to Chekovsky Street, until February 1977. Within rooms having the highest RFR levels (rooms with windows or doors in outside walls toward the irradiation sources), the average power densities were typically about 0.004 mW/cm^2 within 2 ft of a door or window, and 0.0025 mW/cm^2 elsewhere in the room. The highest power density reported was 0.024 mW/cm^2, which occurred in one room during a 2-hr period of unusual signal strength on 24 January 1976.

A study was made of the health of U.S. personnel assigned to the Moscow embassy during the period from 1953 to 1976, compared with the health of those assigned to other U.S. Eastern European embassies. The investigators noted several limitations of the study but were able to conclude that there were no discernible differences between the Moscow and control groups in total mortality or mortality from specific causes, nor were there differences in mortality between the Moscow and control groups of dependent children or adults.

In a study published in 1965 of the causes of Mongolism in U.S. children, an apparent correlation was found between this inherited condition and exposure of the fathers of affected children to RFR before their conception. However, in a later study (1977) in which the original study of 216 children was expanded to 344 children with Mongolism, each matched with a normal child of the same sex born at about the same time and whose mother was about the same age, no such correlation was found. Thus, the earlier conclusion, based on a smaller sample, that exposure to RFR contributed to Mongolism in offspring, was not confirmed. No quantitative assessment of the extent of the fathers' exposures was possible.

The causes of mortality in personnel who had served in the U.S. Navy during the Korean War were monitored in an attempt to establish whether exposure to RFR is associated with causes of death or with life expectancies. By 1977, the records of about 20,000 deceased veterans whose military occupational titles indicated more probable exposure to RFR had been compared with the records of an approximately equal number

of less-exposed veterans. No quantitative exposure data were available. No differences between groups emerged in overall mortality rates or in the rates for about 20 specific categories of cause of death. However, death rates differed significantly for two categories: death rates from arteriosclerotic heart disease were lower and those from trauma were higher in the RFR-exposed group. The trauma category included military aircraft accidents, and a higher proportion of the exposed group had become fliers. It therefore appeared unreasonable to attribute the higher trauma death rate to greater previous RFR exposure. Overall death rates for both groups were lower than those for the general U.S. population of the same age.

The incidences of fetal anomalies and fetal death rates reported in birth records for white children born in the vicinity of the Army Aviation Center at Fort Rucker, Alabama, between 1969 and 1972 were evaluated in a series of three reports. Fort Rucker is of interest because of the concentration of radar units on or near the base. Taken together, these reports identify unusually high incidences of certain fetal anomalies and high fetal death rates in the two counties adjacent to Fort Rucker as compared with the corresponding statewide Alabama statistics, and at the Lyster General Hospital (Fort Rucker) as compared with other military and civilian hospitals. A high incidence of fetal death at the Eglin AFB Hospital is also reported, but no further mention is made of the Eglin data in the remainder of the report. However, there was also evidence that these high rates for Fort Rucker could not be attributed specifically to the unquantified radar exposures at or near Fort Rucker on the basis of the birth record data: Coffee and Dale counties ranked only sixth and eighth for anomaly incidence among the 67 Alabama counties; Lyster Hospital's anomaly and fetal death rates were not significantly higher than several other comparable "non-radar" hospitals in Alabama and were in the range of values predicted from carefully controlled studies done in other states. The residences of mothers bearing anomalous infants were not clustered near radar sites, but many of the anomalies reported at Lyster occurred over a small time period, indicating a high anomaly-reporting rate for one or two physicians on the Lyster staff.

In 1971, a report was published on the results of a battery of medical evaluations carried out on 58 employees of Czech television transmitter stations. Exposure frequencies were estimated to range from 48.5 to 230 MHz at field intensities equivalent to 0 to 0.022 mW/cm^2, with a mean exposure duration of 7.2 years (10.6 hr/workday). Electrocardiograms, heart and lung X-rays, standard blood tests, urinalyses, and liver function tests were conducted, as well as ophthalmologic, neurologic, gynecologic, psychiatric, and psychological examinations. The only statistically significant finding was that the mean plasma protein levels were higher than "normal" values taken from the literature, a finding that the author describes as unexplainable. The appropriateness of the use of literature control values is highly questionable.

In a later study (1974) by the same investigators, the effects of RFR on blood protein levels were reexamined. The authors indicated that

the only difference between exposed and control groups was that the members of the exposed groups had worked irregular shifts, whereas more than half of the control group had worked only morning shifts. The results for both groups showed that the individual levels of blood proteins and their fractions were within normal physiologic limits, but statistically significant differences were found between mean values for the exposed and control groups.

In our opinion, the absence in either study of a control group that had received virtually no RFR exposure renders questionable an interpretation that any differences found were due to RFR exposure. It is likely that the altered values of blood proteins (which were within normal limits) were caused by other factors.

A 1974 report by another investigator in Czechoslovakia was an assessment of workers exposed to RFR at 1-150 MHz, 300-800 MHz, or 3-30 GHz, with power densities, where specified, of 0.1 to 3.3 mW/cm^2, depending on their particular occupations. Changes were reported in brain wave patterns and in blood sugar, proteins, and cholesterol levels, as compared with those in administrative (nonexposed) personnel. The 300-800 MHz range includes the PAVE PAWS frequencies, but no estimates of power density were given in the report.

The authors of a 1974 paper from Poland compared the health status and fitness for work of 507 persons occupationally exposed to pulsed RFR exceeding 0.2 mW/cm^2 average power density (other RFR characteristics not specified) with a group of 334 workers at the same installations exposed to less than 0.2 mW/cm^2. Clinical tests included ophthalmoscopic and neurologic examinations, supplemented by psychological tests and electroencephalograms (EEGs). No statistically significant differences between the two groups were found. In our opinion, the lack of more definitive RFR exposure data vitiates, but does not invalidate, the negative findings of this study; i.e., the results provide no evidence for RFR-induced effects on the health status of either group.

In a USSR paper published in 1974, the authors reported that their clinical examinations of a group of specialists working with RFR generators in the 40- to 200-MHz range for 1 to 9 years showed occurrences of functional changes in the central nervous system, described as vegetative dysfunction accompanied by neurasthenic symptoms. No organic lesions were found, but among the many specific changes reported were deviations in the physiochemical and functional properties of erythrocytes and leukocytes (red and white blood cells). The authors also conducted experiments with human volunteers and reported functional changes in the thermoregulatory and hemodynamic systems and in the thermal, optical, and auditory "analyzers." However, no RFR intensity values were given for either the specialists or the volunteers; most of the findings were presented in narrative form, with no actual data; and the nature of the control group studied was not described. Consequently, this paper provides little basis for affirming or denying the occurrence of possible adverse effects of occupational exposure to RFR.

Another Soviet investigator presented clinical observations on the health status of two groups of USSR RFR workers. Those in the first group (1,000) were exposed to up to a few mW/cm^2, whereas those in the second (180) were exposed to values rarely exceeding several hundredths of a mW/cm^2, both at unspecified "microwave" frequencies. A group of 200 people of comparable backgrounds but presumably not exposed to RFR served as controls. Sixteen kinds of symptoms were reported, including fatigue, irritability, sleepiness, partial loss of memory, lower heartbeat rates, hypertension, hypotension, cardiac pain, and systolic murmur. In the higher-power-density group, the indices for 5 of the 16 symptoms were higher than those in the lower-power-density group; they were lower for 9 symptoms and about the same for the remaining 2. Incidences in the control group were lower than those in either exposed group for 15 of the 16 symptoms.

Several epidemiologic studies have been performed in the United States to ascertain whether chronic exposure to RFR could cause cataracts. As reported in 1961, eye defects were sought in a group of 475 persons who were believed to have been exposed to RFR at 11 military and nonmilitary establishments; a group of 359 persons served as controls. The investigators found a slight but statistically significant difference in defect scores between the two groups, but they expressed some doubt regarding the full validity of the scoring method used.

A 1965 report by several of the same investigators discusses the examination of Veterans Administration Hospital records of 2,946 Army and Air Force veterans of World War II and the Korean War who had been treated for cataracts. A control sample of 2,164 veterans was selected. On the basis of military occupational specialties, they classified each individual as a radar worker, a nonradar worker, or one whose specialty could not be discerned. In the radar group, they found 19 individuals with cataracts and 2,625 individuals without cataracts; in the nonradar group, 21 individuals had cataracts and 1,935 did not. (The remaining 510 subjects were in the unspecified occupational category.) These differences between the radar and nonradar groups are not statistically significant.

In 1966, these investigators reported on statistical analysis of the records of 736 microwave workers and 559 controls for minor lens changes, using a scoring range from 0 to 3. They reported that the defect scores increased with age for persons in both groups, but that the average score for the microwave group was significantly higher than for the control group. They suggested that this finding is an indication that exposure to RFR may have an aging effect on the lens. However, no cataracts or decreases in visual acuity were found.

In a study published in 1973, which covered a period of 5 years, military personnel identified as having been occupationally exposed to RFR from radar and communications systems were matched as closely as possible in age and sex with other military personnel on the same bases who had not been occupationally exposed. Several ophthalmologists

independently examined exposed and control personnel (without knowledge of the group to which each individual belonged) for opacities, vacuoles, and posterior subcapsular iridescence, taken as diagnostic precursors of cataracts. Each precursor was scored as either present or absent in each individual, and the binary data thus obtained were used for statistical analyses by age group and numbers of persons per age group. The results indicated that more people in older age groups exhibited these precursors, but the pooled data from several Army installations showed no statistically significant differences between exposed and control groups.

As in other epidemiologic studies, the accuracy and detail of the exposure histories (frequencies, intensities, durations, and so on) taken for either the exposed or the control groups in these three ocular studies are difficult to determine. However, the exposed groups quite likely did receive more RFR exposure than the control groups.

In summary, none of these U.S., Polish, and Czechoslovakian epidemiologic studies offers clear evidence of detrimental effects associated with exposure of the general population to RFR. However, the Soviet findings, which are consistent with the voluminous, early Soviet literature, suggest that occupational exposure to RFR at average power densities less than 1 mW/cm^2 does result in various symptoms, particularly those associated with disorders of the central nervous system (CNS). Because the USSR symptomatology has not been reported in Western studies and because of the marked differences between Soviet and Western publications in the procedures used for reporting data, any prediction of possible RFR hazards based on the USSR epidemiologic studies would require acceptance of these Soviet findings at face value. We conclude that, taking all of the epidemiologic studies together, the results do not provide evidence that the RFR from SEPP will be hazardous to the population outside the exclusion fence.

4.1.1.2.6.2 Mutagenesis and Cancer Induction. One frequently expressed concern about RFR is that it may cause mutations. Mutagenesis and cancer induction are considered to be related, and indeed many chemicals are screened for potential cancer-causing properties by using bacterial mutation tests. Several studies for mutagenic effects have been carried out on bacteria, yeast, and fruit flies (standard test systems for mutagenesis). All of these studies failed to demonstrate a mutagenic effect. No mutations attributable to RFR exposure were found.

Another standard test system for mutagenesis is the so-called dominant lethal assay in which mutations result in the death of the embryo. Two studies in mice (both done by the same investigator at approximately the same time) gave marginal positive evidence of mutation. Certain aspects render these findings dubious, however. First, there was a large difference in the incidence of naturally occurring mutations between the two studies. By comparison, exposure produced very small increases in the incidence of mutations. If the value given for the natural incidence shows large variability from one study to the next, it is likely that an uncontrolled factor rather than RFR caused the observed mutations.

Second, the mice used were anesthetized during exposure. Anesthesia in mice blocks the normal mechanisms for control of body temperature. Temperature rise in the testes of exposed mice might have been higher than if they were unanesthetized. Because heat is known to be mutagenic in such tests, any true mutations may have resulted from overheating of the testes.

Another study of dominant lethal mutations, in unanesthetized rats, failed to find evidence of mutagenic effects. However, temporary sterility, as indexed by fewer pregnancies, was seen at power densities of 28 mW/cm^2 but not at lower power densities. The 28-mW/cm^2 level caused a significant increase in rectal and intratesticular temperatures.

Studies have been carried out on the effects of RFR exposure on the structure of chromosomes in cells. The occurrence of chromosomal aberrations is considered as indicating the possibility of genetic effects but not as absolute proof of such effects. In one study on garlic root tips, chromosomal aberrations were found, but the description of the exposure conditions was only sketchy. Power density could have ranged as high as 600 mW/cm^2. Another study involved Chinese hamster cells and human amnion cells. Exposure to RFR did not induce aberrations. In another study, effects were seen in human lymphocyte cells, but only at power densities of 20 mW/cm^2. In still another study, effects were seen in Chinese hamster cells reportedly exposed to 200 and 500 mW/cm^2, but these power densities likely were incorrect, casting doubt on the conclusions of the study. Two other studies investigated effects of RFR on sister chromatid exchange in Chinese hamster ovary cells and bone marrow cells of mice. Production of sister chromatid exchange was not related to RFR exposure.

Two papers reported studies on the effects of RFR on mechanisms involved in the repair of cellular deoxyribonucleic acid (DNA). After ultraviolet was used to damage DNA of normal human fibroblasts, RFR caused no alteration in the DNA repair process. Similarly, when mice were treated with streptozocin, a mutagenic/carcinogenic agent known to damage the DNA in rodent liver cells, exposure to RFR did not alter the level of DNA repair.

One paper has claimed an association between RFR exposure and cancer incidence. The study involved chronic daily exposure of mice to brief, high-power-density RFR. An increase in leukemia was claimed. Reexamination of the study indicates that it was improbable that the leucosis (an increase in the number of white blood cells) observed was actually leukemia.

Two other studies of chronic irradiation of mice and rats showed no effects of the exposure on a variety of general indications of health or on the occurrence of cancer.

In summary, all of the studies on mutagenic and cytogenetic effects of RFR exposure reviewed here indicate that the effects found are probably related to heating. Power density levels outside the SEPP

exclusion area are incapable of producing significant heating. There is no evidence that such low power densities are likely to cause mutagenic effects. In addition, a report claiming that RFR exposure has increased the incidence of cancer does not stand up to critical review: It does not provide evidence that exposure to RFR is likely to cause cancer. Other studies have failed to find an effect of RFR exposure on the general health of the exposed animals or on the occurrence of cancer.

4.1.1.2.6.3 Studies on Teratogenesis and Developmental Abnormalities. Teratogenesis in humans is the production of malformed infants by processes affecting their development in the womb. The term, "developmental abnormalities," as used here refers to processes affecting the development of infants after birth. Teratogenic and developmental abnormalities occur naturally at a low rate in most animal species, and relatively little is known about their cause. In a few cases, however, specific agents have been shown to cause significant teratogenic effects; hence, the possibility of teratogenic effects from RFR is an appropriate matter of public concern.

Teratogenic studies with RFR have used a variety of animal models. One set of studies was performed on pupae of the darkling beetle, *Tenebrio molitor*. Several reports from different laboratories stated that relatively low levels of RFR would produce developmental abnormalities in the pupae. A follow-up study in one of the laboratories, however, reported that the number of developmental anomalies depended on such factors as the source of the larvae and the diet fed to them before they entered the pupal stage. This study also reported that production of developmental anomalies under worst conditions required exposure for 2 hr at a mean SAR of 54 W/kg (approximately equivalent to 192 mW/cm^2).

Japanese-quail eggs were exposed to 2.45-GHz CW RFR at 5 mW/cm^2 (SAR of about 4 W/kg) for 24 hr/day during the first 12 days of development. The investigators found no gross deformities in the quail when euthanized and examined 24-36 hr after hatching, and no significant differences in total body weight or the weights of the heart, liver, gizzard, adrenals, and pancreas between RFR- and sham-exposed groups. Blood tests showed statistically significant higher hemoglobin (contained in red blood cells and important in oxygen transport) and lower monocyte (a form of white blood cell) counts in the RFR-exposed birds, but no differences in the other blood parameters. The differences in mean temperature from egg to egg in the RFR-exposed arrays were as much as 0.5 deg C, rendering it difficult to associate these positive findings with RFR per se. In another study by the same investigators, groups of eggs were similarly exposed and the birds were reared for 5 weeks after hatching. No significant differences in mortality or mean body weights at 4 and 5 weeks were found between RFR- and sham-exposed groups.

Teratogenic effects of RFR have been reported in several studies in mice and rats. In an early major study, pregnant mice were exposed on day 8 of pregnancy (gestation) to 2.45-GHz RFR at 123 mW/cm^2 for 2 to 5 min, corresponding to doses in the range 3-8 cal/g. On gestational day 18, the litters were examined for resorptions, and for dead, stunted,

malformed, and apparently normal fetuses. No abnormalities were reported at doses less than 3 cal/g, which correspond to about 25 to 30% of the lethal dose for these animals. At doses above 3 cal/g, some abnormalities were obtained, notably exencephaly, a disorder in which the skull does not close and the brain is exposed ("brain hernia").

In another investigation, pregnant mice were exposed to 2.45-GHz RFR for 100 min daily on gestational days 1 through 17 at 3.4 to 14.0 mW/cm^2, or on gestational days 6 through 15 at 28 mW/cm^2. Control mice were sham-exposed similarly. All mice were euthanized on day 18 and their uteri were examined for the number of resorbed and dead conceptuses and live fetuses. The live fetuses were examined for gross structural alterations and weighed. Ten types of anomalies were tabulated by the numbers of litters affected. A total of 27 of the 318 RFR-exposed litters, irrespective of power density, had one or more live abnormal fetuses, versus 12 of the 336 sham-exposed litters. For most of the individual anomalies, the numbers of litters affected were either too small for statistical treatment or no RFR-related pattern was apparent. The mean live fetal weights of the litters exposed at power densities of 14 mW/cm^2 or lower were not significantly different from those of the corresponding sham-exposed litters. The latter finding was confirmed in a subsequent study by these investigators. In addition, some of the mice exposed at 28 mW/cm^2 were permitted to come to term, and the mean weight of their offspring at seven days of age was found to be about 10% less than that of control mice. However, there were no differences in survival rate between RFR-exposed and control offspring.

Other studies with pregnant mice at sublethal exposure levels yielded both comparable and conflicting results, presumably because of differences in experimental apparatus and procedures, but no evidence that doses less than 3 cal/g or power densities less than 1 mW/cm^2 are teratogenic.

Several similar studies were conducted with pregnant rats. In a representative recent study, 70 rats were exposed to 2.45-GHz CW RFR for 100 min daily on gestational days 6 through 15 at 28 mW/cm^2 (estimated SAR of 4.2 W/kg). The mean colonic temperature at the end of each exposure period was 104.5 deg F (40.3 deg C). A group of 67 rats was similarly sham-exposed. No significant differences between groups were found in: pregnancy rates; numbers of live, dead, or total fetuses; incidences of external, visceral, or skeletal anomalies or variations; or body weight of live fetuses. The investigators surmised that this lack of an effect may hold true at any exposure level less than that which will kill a significant number of the dams by hyperthermia (colonic temperature greater than 40 deg C).

In an investigation under way, 10 rats were exposed essentially continuously for 16 days to 2.45-GHz pulsed RFR with a pulse duration of 10 microseconds and 830 pps. The average-power SAR was held constant at 0.4 W/kg. Ten other rats were sham-exposed. In the two series of exposures performed thus far, none of the rats was allowed to come to term. Instead, their uteri were removed and examined. In a preliminary

analysis of the data, no gross visual or histological abnormalities or differences in number of offspring between the RFR- and sham-exposed groups were evident.

In a study designed primarily for seeking possible effects of chronic RFR exposure on mother-offspring behavioral patterns and the EEG, 33 female squirrel monkeys were exposed near the beginning of the second trimester of pregnancy to 2.45-GHz RFR at whole-body SARs of 0.034, 0.34, or 3.4 W/kg (the last value equivalent to about 10 mW/cm^2 of plane-wave RFR) for 3 hr/day, 5 days/week, until parturition. Eight pregnant monkeys were sham-exposed for the same periods. After parturition, 18 of the RFR-exposed dams and their offspring were exposed to RFR for an additional 6 months; then the offspring were exposed without the dams for another 6 months. No differences were found between RFR- and sham-exposed dams in the numbers of live births or in the growth rates of the offspring. The major difference between RFR- and sham-exposed offspring was that four of the five exposed at 3.4 W/kg both prenatally and after birth unexpectedly died before 6 months of age, but the mortality values were too small to place much confidence in statistical inferences. A follow-up study of mortality per se, which involved sufficient numbers of squirrel monkeys for adequate statistical treatment, did not confirm the RFR-induced offspring mortality results.

In summary, the studies showing demonstrable teratogenic effects following exposure to RFR have involved power density levels that are capable of producing a significant heat load in the animals. In general, the results indicate that a threshold of heat induction or temperature increase must be exceeded before teratogenic effects are produced. Because the heat-load increase in humans from RFR exposure at the average power densities outside the SEPP exclusion fence will be very small relative to the normal metabolic rate of about 1 to 2 W/kg, teratogenesis from such exposure is not likely to occur.

4.1.1.2.6.4 Ocular Effects. The fear that RFR can cause cataracts is a recurring theme in newspapers and other popular media. Indeed, based on many investigations with animals by various researchers, it is undoubtedly true that if a person's eyes were exposed to intensities high enough to elevate the temperature of the lens by about 5 deg C (9 deg F) or more, the lens would quickly suffer damage. The lens is the region of the eye most vulnerable to RFR because other regions have more effective means of heat removal, such as greater blood circulation, evidenced by much smaller temperature elevations in these regions than in the lens at the same incident power density. Therefore, the basic controversy regarding ocular effects is centered on whether exposure to much lower intensities (i.e., to power-density levels that would produce much smaller lens temperature elevations) for long periods of time, either continuously or intermittently, can cause eye damage. Implicit in this controversy is the issue of whether effects (if any) of long-term, low-level exposure in the eye are cumulative.

4.1.1.2.6.4.1 Humans. Some cases of ocular damage in humans ascribed to occupational exposure to RFR were reported during the 25 years after

World War II. Although the exposure histories of these individuals could not be ascertained with any degree of certitude, their actual or incipient vision impairment probably resulted from exposure to average power densities substantially greater than the threshold found in animal studies (about 150 mW/cm^2).

The occurrence of cataracts in two editors with the New York Times was ascribed, in newspaper accounts during 1977 and 1978, to their exposure to supposed RFR from the cathode-ray tubes in video-display terminals used by them. Cases of RFR-induced birth defects and abortions were also linked, in other newspaper stories, to exposure to video terminals. The New York Times arranged for measurement surveys of the terminals in question. These surveys yielded negative results; the only measurable radiations emitted by the terminals were well above the RFR spectrum. Independent surveys of the same terminals by personnel from NIOSH confirmed these findings.

Epidemiologic studies have been conducted to determine whether prolonged exposure to RFR is cataractogenic. These studies are discussed in Section 4.1.1.2.6.1.

4.1.1.2.6.4.2 Animals. During the past 30 years, various investigations have been conducted on the effects of RFR exposure on the eyes of live experimental animals. Many of the results indicate that intraocular temperature increases of about 5 deg C or more are necessary for eye damage. Also, lens opacifications caused by RFR exposure alone were not produced at the same average power density when the eye was cooled during exposure.

Many of the results of RFR exposure indicate the inverse relationship between average power density and exposure duration for cataract formation and the existence of a threshold average power density of about 150 mW/cm^2 for single or multiple exposures for tens of minutes or more.

Several investigators compared the ocular effects of pulsed and CW RFR at equivalent average power densities. In representative investigations, the average power densities were greater than 100 mW/cm^2 and the exposures were for about 1 hr/day for several weeks. No significant differences between the effects of pulsed and CW RFR were found.

The existence of a cataractogenesis threshold implies that single or multiple exposure for indefinitely long durations at average power densities well below the threshold would not cause eye damage to humans or any other species.

In summary, based on the experimental results with animals indicating the existence of a threshold power density of 150 mW/cm^2 and the finding of no statistically significant differences between exposed and control groups of humans on military bases, there is no evidence that prolonged exposure of humans to the RFR from SEPP at the power densities outside the exclusion area is likely to cause eye damage.

4.1.1.2.6.5 Studies of the Nervous System. Several types of studies have been conducted on effects of RFR on the nervous system of animals. These studies are considered particularly important in the USSR, where RFR is believed to stimulate the nervous system directly and thereby cause a variety of physiological effects. U.S. scientists tend to doubt that RFR interacts directly with the nervous system except, possibly, under special circumstances (to be discussed later in this section); they consider most effects of RFR on the nervous system to be indirect results of other physiological interactions.

4.1.1.2.6.5.1 RFR Hearing Effect. Humans in the vicinity of some types of pulsed radar systems have perceived individual pulses of RFR as audible clicks (without the use of any electronic receptors). This phenomenon has attracted much interest--especially in the United States--because it has often been cited as evidence that nonthermal effects can occur and because an initial hypothesis was that one possible mechanism for perception is direct stimulation of the central nervous system by RFR. Various theoretical and experimental studies, the latter with both human volunteers and laboratory animals, have been conducted to determine the conditions under which pulsed RFR is audible and to investigate the interaction mechanisms involved. Many of the results support the hypothesis that an RFR pulse having the requisite pulse power density and duration can produce a transient thermal gradient large enough to generate an elastic shock wave at some boundary between regions of dissimilar dielectric properties in the head, and that this shock wave is transmitted to the middle ear, where it is perceived as a click. Persons with impaired hearing are unable to hear such clicks, and experimental animals in which the cochlea (the inner ear) has been destroyed do not exhibit brainstem-evoked responses.

Investigators used 3.0-GHz RFR to study the auditory effect in two cats, two chinchillas, one beagle, and eight human volunteers. For the animals, surface or brainstem-implanted electrodes were used to measure the responses to RFR pulses and the responses evoked by audio clicks from a speaker. They found that perception of 10-microsecond pulses required pulse power densities of at least 1.3 W/cm^2 for both cats, 1 and 2 W/cm^2 for the two chinchillas, and 300 mW/cm^2 for the beagle.

The eight humans were given standard audiograms. Because such audiograms do not test hearing above 8 kHz, binaural hearing thresholds were also determined for seven of the subjects for frequencies in the range from 1 to 20 kHz. Five of the subjects could detect 15-microsecond pulses as clicks; the other three required a pulse duration of 200 microseconds for perception. No correlation between the results and the audiograms was apparent; however, there was a strong correlation between RFR perception and hearing ability above 8 kHz as determined from the binaural thresholds. The average threshold pulse power density for 15-microsecond pulses was about 700 mW/cm^2; however, three of the subjects were able to perceive 15-microsecond pulses at a pulse power density of 300 mW/cm^2, a value taken herein as representative for humans. Thus, humans at ground level outside the SEPP exclusion fence would not likely "hear" the RFR pulses. However, airborne people in the main beam

of the radar may hear the pulses if they approach closer than about 3,200 ft. Within this range, the pulse power density in the main beam will not exceed about 900 mW/cm^2. It should be noted that these investigators exposed the human volunteers to pulse power densities as high as 2,000 mW/cm^2 without apparent ill effects.

4.1.1.2.6.5.2 Calcium Efflux. Exposure of brain-tissue samples from newly hatched (neonatal) chicks to RFR amplitude-modulated at low frequency has been reported to increase the rate of exchange of calcium ions between the tissue and the fluid bathing it. This effect has been demonstrated by two groups of investigators for modulated carrier frequencies of 50, 147, and 450 MHz, as well as for exposure to the modulation signal (16 Hz) alone, but not for unmodulated 50-, 147-, or 450-MHz RFR. Incident power densities that are effective in altering the rate of calcium exchange lie between approximately 0.1 and 3.6 mW/cm^2. However, within this range, not all power densities are effective. There appear to be narrow, effective power density "windows." Calculations of internal field intensity appear to indicate that this factor is important in predicting effectiveness. The mechanisms whereby modulation effects are mediated are speculative. Of additional interest is a report that 16-Hz amplitude-modulated 147-MHz RFR at 2.0 mW/cm^2 increases calcium efflux from pancreatic tissue slices to approximately the same extent as that from neonate chick brain tissue incubated and exposed under similar conditions. An attempt to obtain alterations in calcium efflux from rat brain tissue by use of pulse-modulated 1-GHz RFR was unsuccessful. It is uncertain whether these negative findings were a result of differences in brain tissue, exposure parameters, carrier frequency, or type of modulation.

All of the above studies were carried out on isolated tissues maintained in physiological solutions. A recent study has reported that similar alterations in calcium ion exchange occur for exposed brains of paralyzed live cats irradiated at 3 mW/cm^2 with 450-MHz RFR sinusoidally amplitude modulated at 16 Hz.

The effect is scientifically interesting in that it represents a rare instance where RFR may be producing a biological effect by processes other than thermal mechanisms. Interpreting these results with regard to human health and safety is difficult. First, the phenomenon is subtle. Large numbers of samples have to be processed to show a statistically significant effect. Second, the observations are highly variable and difficult to reproduce. Third, the circumstances of the experimental methodology are such that the observations of changes of calcium exchange appear to apply to the surface region of the brain rather than to the brain as a whole. Finally, the phenomenon depends on the amplitude modulation of the RFR in a narrow frequency band around 16 Hz and occurs only for narrow ranges of average power densities (windows) between 0.1 and 3.6 mW/cm^2. Nevertheless, because this range is above the levels of general public exposure from SEPP, the occurrence of this effect in humans is unlikely.

4.1.1.2.6.5.3 Blood-Brain Barrier Effects. In most organs and tissues of the body, molecules in the blood can freely diffuse into the tissue around the capillaries. However, presumably to protect the brain from invasion by various blood-borne microorganisms and toxic substances, large molecules such as proteins or polypeptides exhibit little or no movement from the blood into the surrounding brain tissue in most regions of the brain. The exact manner by which the movement is prevented is still conjectural, but the process is referred to as the "blood-brain barrier" (BBB). The BBB can be "opened" by certain agents (e.g., ionizing radiation, heat) or chemical substances (e.g., DMSO). Studies have been conducted to examine whether RFR also can alter the BBB permeability of animals to various large molecules.

Four studies by two separate research groups have reported gross permeability increases in the rat BBB when the brain temperature was raised significantly (e.g., several degrees) by RFR heating, or, equivalently, the local SAR was several hundred watts per kilogram. Other researchers found scattered regions in the brain displaying permeability changes for 2-hr exposure at 10 mW/cm^2. Twenty percent of the sham-exposed animals also showed these changes, which were reversible. The 10 mW/cm^2 value may represent the lower limit at which local regions of the brain are heated.

One study reported alterations in BBB permeability to fluorescein by use of pulsed RFR at average power densities as low as 0.2 mW/cm^2. These findings could not be repeated by three other groups using fluorescein and similar experimental procedures.

Another study reported increased BBB permeability to radiotracer-labeled molecules at average power densities less than 3 mW/cm^2, with pulsed RFR more effective than CW RFR. Three other research groups could not repeat those findings. Subsequently, the researchers first reporting the effect used a higher average power density (15 mW/cm^2) and different techniques, and showed that their original findings could be explained as an increase in local cerebral blood flow rather than as an increase in BBB permeability. (Local cerebral blood flow can be altered in humans by mental activity in the absence of external physical stimuli.)

In summary, RFR can alter BBB permeability at exposure levels sufficient to cause heating of the brain. Exposure to levels considered insufficient to cause heating (below several mW/cm^2) have also been reported to alter BBB permeability, but these results have not been confirmed, despite several independent attempts to do so. In one case, the original findings may have arisen as a consequence of the experimental techniques used. On the basis of the evidence available, it is very unlikely that exposure of people to the levels of RFR existing at ground level outside the exclusion fence of SEPP would have any effect on the permeability of the BBB.

4.1.1.2.6.5.4 Histopathology and Histochemistry of the Central Nervous System (CNS). Histopathology is defined as the study of diseased or

damaged tissues, and histochemistry as the study of the chemical composition of various tissues. Studies of histopathological effects of RFR on the brain have been conducted in both the United States and the USSR. Studies in the USSR have covered a wide range of frequencies, but the dosimetry and methods were inadequately reported in many instances. Exposure of animals (predominantly rats) to RFR between 500 MHz and 1 GHz (no additional information on frequency) at 10 mW/cm^2 for 1 hr/day for 10 months resulted in various changes from the normal appearance of nerve cells of the brain, as detected by delicate elective neurohistological methods (not otherwise specified). The authors reported that the power density did not raise body temperature, but current knowledge indicates that the method of exposing the animals was such that the SAR must have varied considerably among the animals. The reported changes in appearance were similar to those found in other experiments of a frankly thermal nature (20 to 240 mW/cm^2), and it is most probable that the reported effects in the chronic exposure experiments were also of thermal origin.

In the United States, a study of the histopathological effects of RFR on the brain was performed on hamsters exposed to 2.45-GHz RFR at power densities between 10 and 50 mW/cm^2 for periods between 30 min and 24 hr. Chronic exposures were also carried out at similar power densities over a period of 22 days. In this study pathological changes were found only in the hypothalamus and subthalamus, two regions near the center and base of the brain. Comments after oral presentation of this study noted that the nature of RFR absorption inside the skull of such a small animal at the frequency used could lead to regions in the brain where the SAR would be tens of times higher than that expected from the nominal power density, and that rectal temperature measurements in the animals would not reflect such a condition. The observed pathological effects seem likely to have resulted from thermal processes. Quantitative studies on the effects of RFR at relatively high levels (10 to 46 mW/cm^2, SAR approximately 2 W/kg) on rat Purkinje cells of the cerebellum (a distinctive cell type in this region of the brain) showed that RFR exposure pre- and postnatally caused a significant decrease in numbers of these cells. However, a similar study using squirrel monkeys did not show such an effect. Size differences between the heads and brains of the rat and squirrel monkey may have resulted in high local SAR in regions of the rat brain, but not in similar regions of the squirrel monkey brain, again indicating that the observed effects seem likely to have resulted from thermal processes.

Two studies were reviewed that examined effects of RFR on brain neurochemistry. One showed no effects on specific neurotransmitters of mouse brain at 19 MHz for near-field exposure conditions of 6 kV/m (E field) or of 41 A/m (H field) for 10 min. The other showed a sequence of small (5 to 10%) changes of biochemical activity in subcellular components associated with tissue respiration at exposure levels of 5 and 13.8 mW/cm^2. The significance of these latter findings is unclear, but they are unlikely to be indicative of a hazard because of the wide range of tissue respiration values possible under various environmental and activity situations.

In summary, RFR can cause observable histopathological changes in the CNS of animals, but these changes appear to be thermal in nature. Under special conditions of frequency and skull size, a focusing effect can be obtained in small rodents, causing local SARs tens of times higher than would normally be expected from whole-body SAR measurements. Such conditions do not occur for the adult human skull. One study has reported small changes in brain-tissue respiratory chain function at a power density of 5 mW/cm^2. It is unlikely that such effects would be detectable at the power densities at ground level outside the SEPP exclusion fence. These studies provide no evidence that exposure to such power densities are likely to be hazardous.

4.1.1.2.6.5.5 EEG Studies. Studies have been conducted to ascertain the effects of RFR on the EEG or other related electrophysiological properties of the CNS. For EEG measurements made after RFR exposure, the time consumed in placing and attaching the electrodes and the variability of placement introduce problems of interpretation. Additionally, if the effects are transient, they may stop when exposure ceases. For studies attempting to measure EEG changes during application of the RFR, the electrodes and leads used to pick up EEG signals also pick up electrical signals directly from the fields, causing artifacts that render the recordings difficult to interpret. In addition, indwelling or chronically attached electrodes will perturb the electric fields in their vicinity and produce great enhancement of energy absorption, thereby creating still another artifact in the biological data. To meet these problems, specially designed indwelling electrodes of high-resistivity materials that do not cause field perturbation have been constructed and used in a few of the more recent studies.

Two groups of researchers, using implanted metallic electrodes, reported changes in EEG patterns after acute or chronic exposure of rabbits to RFR. Another group, using implanted electrodes made of carbon instead of metal (an attempt to avoid the field distortion artifact), reported no significant differences in EEG between irradiated and control rabbits after 3 months of RFR exposure (1.5 mW/cm^2, 2 hr/day). Another study, using electrodes externally placed after exposure rather than indwelling ones, reported no differences in EEG pattern between control and RFR-exposed monkeys after more than 12 months of exposure. A study of rats exposed to RFR from before birth to age 92 days (indwelling electrodes again not used) showed no differences from control animals when both groups were tested at 140 days of age. Lastly, the EEGs of rabbits having indwelling carbon-loaded Teflon (high resistance) electrodes were examined before and during exposure to 2.45-GHz RFR at 100 mW/cm^2 (SAR of about 25 W/kg at the electrodes), and no obvious differences were found.

In summary, the use of indwelling metallic electrodes in studies of the effects of RFR on the EEG or on evoked potentials of the CNS may be questioned as a procedure likely to introduce artifactual effects in the preparation under study, as well as in the recordings themselves. These artifacts may be minimized by use of electrodes appropriately designed from high resistivity materials. Experiments in which such specially

constructed electrodes were used, or in which electrodes were applied after exposure, show no evidence of statistically significant differences in EEGs or in evoked responses between control and RFR-exposed animals. There is no evidence that ground-level RFR from SEPP is likely to cause any effects on the EEG or evoked potentials of populations outside the exclusion fence. Based on one study, persons with indwelling metallic electrodes in the brain or prosthetic metallic plates on the skull may have effects induced in their EEGs or evoked potentials in the vicinity of the exclusion fence, where the highest average power density is approximately 0.1 mW/cm^2, but only if they were there for extended periods (several months).

4.1.1.2.6.6 Effects on Behavior. Many experimental studies have been conducted on the effects of RFR on animal behavior. The results of such studies are considered particularly important in the USSR, where they are often considered to be evidence for direct effects of RFR on the CNS. Scientists in the United States do not always agree that behavioral effects necessarily imply direct effects on the CNS. However, behavioral effects are very sensitive indicators of biological function and hence receive appropriate attention in both Eastern European and Western countries. The papers described in the RFR-bioeffects review were selected as representative of the types of behavioral studies that have been conducted. These include studies of effects on reflex activity, RFR-perception studies, evaluations of effects of RFR on learning and on performance of trained tasks, studies of interactive effects of RFR and drugs on behavior, and investigations of behavioral thermoregulation. Studies have been conducted on mice, rats, rabbits, squirrel monkeys, rhesus monkeys, and humans.

Soviet studies have claimed that exposure of rats to RFR at power densities as low as 0.01 mW/cm^2 for 10 days or more have resulted in disturbance of many inborn forms of behavior, including conditioned reflex activity. The validity of these claims is difficult to assess, however, because the reports of the experiments lack details. Attempts were made to repeat the studies in the United States, but using higher power densities. No effects on reflex development were seen at power densities up to 10 mW/cm^2 for durations up to 92 days. Soviet reports of effects at low (equal to or less than 0.5 mW/cm^2) power densities under long-term exposure conditions and the absence of similar effects in the same or higher power-density range in the studies of U.S. researchers have appeared frequently in the RFR bioeffects literature.

The RFR hearing effect is, by definition, perception of pulsed RFR. Other studies of CW or modulated RFR have been conducted to determine whether perception can serve as a behavioral cue, and some have indicated that rats modify their behavior in response to pulsed RFR at average power densities as low as 0.2 mW/cm^2. As discussed in Section 4.1.1.2.6.5.1, however, average power densities are meaningless in the perception of pulsed RFR. Pulse power density is the meaningful parameter, and humans appear to be able to perceive pulse power densities of about 300 mW/cm^2 and higher. By contrast, CW RFR is an extremely feeble perceptual cue, with tens of milliwatts per square centimeter

(average power density) necessary to modify behavior, unless the RFR is accompanied by other perceptual cues such as light or sound. This is borne out in studies on humans, where the threshold for perception of warming of the skin is 27 mW/cm^2.

Acute exposure to RFR will suppress performance of learned tasks and the learning of new tasks in rats, squirrel monkeys, and rhesus monkeys at sufficiently high power densities (generally 5 mW/cm^2 and up). The effect depends on duration of exposure, animal species, frequency of RFR, power density, and demand characteristics of the behavior. A reasonable conclusion is that suppression of learned behavior tasks depends on the amount and distribution of energy absorbed by the animal. Chronic exposure produces similar results, but with a slight reduction in minimum power density required (1 mW/cm^2 and up).

Studies on the interaction of RFR and drugs in rats that affect the CNS have yielded interesting results. Pulsed 2.45-GHz RFR at an average power density of 1 mW/cm^2 (SAR of 0.2 W/kg) was found to enhance the effects of dextroamphetamine, a CNS stimulant, and chlordiazepoxide and pentobarbital, CNS depressants. By contrast, pulsed 2.8-GHz RFR at 1 mW/cm^2 did not produce any alterations in the behavioral dose-effect functions of chlorpromazine or diazepam, two other commonly prescribed CNS depressant drugs. Mechanisms of this synergism between RFR and certain drugs, but not others, are unclear at present.

Studies specifically designed to examine thermoregulatory behavior in rats and squirrel monkeys using 2.45-GHz RFR, have shown alterations in behavior at power densities from 5 to 20 mW/cm^2 in the rat and at 6 to 8 mW/cm^2 in the squirrel monkey. In addition, mice have been shown to orient themselves to reduce the percentage of RFR as sound energy absorbed where they might otherwise have become overheated. Behavioral thermoregulation depends on the existing environmental situation. The 5-mW/cm^2 level appears to be the threshold value necessary to elicit a behavioral thermoregulatory response.

In summary, RFR is capable of producing alterations in a wide variety of behaviors of various species of animals. Except for pulsed RFR, average power densities required to modify behavior are almost all at levels of approximately 5 mW/cm^2 and above, and most appear to be in the thermal range. Perception of pulsed RFR as sound is a peak power phenomenon, not one of average power. It is difficult to relate most of the behavioral studies in animals to humans. All behavioral studies are directly relevant to the nature of the species being studied, and the conclusions of a given study do not readily transfer to other species. Because of the power densities needed to cause reported effects, however, these studies provide no evidence that exposure to RFR at the levels outside the SEPP exclusion fence is likely to have adverse effects on human behavior.

4.1.1.2.6.7 Endocrinological Effects. Exposure of animals to RFR has produced somewhat inconsistent effects on the hormone-secreting

(endocrine) system of mammals. In general, the effects produced appear to be related to either the heat load associated with the RFR or the stress induced in the animals by the RFR and, possibly, other experimental circumstances. Some effects also appear to be related to alteration of the circadian rhythm by RFR. There do not appear to be any effects clearly demonstrated to be associated with nonthermogenic stimulation of the endocrine system or the associated parts of the CNS.

Because of the known sensitivity of the testes to heat, several investigations of the effects of RFR on gonadal function have been conducted. In one early study, mice were exposed to 9.27-GHz RFR at 100 mW/cm^2 for 4.5 min/day (which increased mean body temperatures by 3.3 deg C) for 5 days/week over 59 weeks. Testicular degeneration was found in 40% of the RFR-exposed and in 8% of the control mice that had died during the course of the experiment. Recently, other investigators reported that exposure of mice to 2.45-GHz RFR at 20 to 32 mW/cm^2 for 16 hr/day for 4 days had no effect on sperm count or percentages of abnormal sperm.

In another recent investigation, the rear halves of anesthetized mature male mice were exposed to 2.45-GHz RFR for 30 min at half-body SARs ranging from 18 to 75 W/kg, which produced elevated rectal temperatures. For comparison, the rear halves of other anesthetized mice were immersed for 30 min in a well heated to yield comparable rectal temperatures. Extensive degeneration of the sperm-generating cells was evident for RFR exposure at 75 W/kg and for well heating to 45 deg C. At SARs of 37 W/kg or lower or a well temperature of 37 deg C, no effects were seen. Measurements of testicular temperature indicated the existence of a threshold of about 39 deg C for depletion of spermatocytes and of about 41 deg C for 50% cell death after 6 days of RFR exposure or direct heating. The corresponding SARs for these two thresholds were 20 and 30 W/kg.

Men occupationally exposed to RFR in the 3.6- to 10-GHz range at power densities of tenths to hundredths of a mW/cm^2 for 1 to 17 years (a mean of 8 years) were reported to show slightly reduced sperm counts, but normal plasma levels of hormones that control the functioning of the gonads.

Stimulatory effects on the thyroid glands of dogs were obtained from local exposure of one of the two thyroids to 2.45-GHz RFR for 2 hr at 72, 162, or 236 mW/cm^2. The SARs in the exposed gland were 58, 121, and 190 W/kg, respectively, and the corresponding temperatures were about 102, 106, and 113 deg F. In response, the exposed glands increased their output of thyroxine (a hormone that controls the metabolic rate in other cells) by factors of 1.5, 3.5, and 10, an effect attributed to the temperature rise. At the levels of RFR outside the SEPP exclusion fence, no temperature rise would occur; therefore, this effect would be absent.

The necessity for minimizing stresses induced in rats by factors other than RFR by allowing them to become accustomed to the experimental

situation ("gentling" them) before RFR exposure was demonstrated in several investigations. With the use of such a procedure, endocrinological effects ascribable to RFR exposure can be more readily discerned from those due to non-RFR stresses, but the latter are difficult to eliminate entirely. In a recent study, gentled rats were exposed to 2.45-GHz RFR at power densities ranging from 1 to 70 mW/cm^2 (equivalent SARs of 0.21 to 14.7 W/kg) for periods ranging from 1 to 8 hr at an environmental temperature maintained at 24 deg C. Sham-exposed rats were used as controls. After treatment, the rats were decapitated, colonic temperatures were taken, and blood was collected for assays of thyroxine, thyrotropin (a hormone secreted by the pituitary gland), growth hormone (also secreted by the pituitary), and corticosterone (secreted by the adrenal gland). For exposures of 1 hr, colonic temperatures increased with power density at 20 mW/cm^2 and higher, but consistent elevation of serum corticosterone did not occur below 50 mW/cm^2. Lower serum thyrotropin and growth hormone levels also occurred at this and higher power densities. For sham exposures and exposures at 1-20 mW/cm^2 for longer durations (2-8 hr), the results were rather equivocal, presumably because such exposures encompassed significant portions of the circadian cycle.

Exposure of warm-blooded animals to RFR has been found to affect their involuntary thermoregulatory mechanisms. In a recent study, squirrel monkeys were exposed to 2.45-GHz CW RFR for 10 min or 90 min in relatively cool ambient temperatures of 59, 68, or 77 deg F. The power densities ranged from 2.5 to 10 mW/cm^2 (SARs from 0.4 to 1.5 W/kg). The metabolic heat production was calculated from the oxygen deficit in the expired air of each monkey. At all three ambient temperatures, 10-min exposures of two monkeys to a threshold power density of 4 mW/cm^2 and one monkey to 6 mW/cm^2 reliably initiated a reduction of their metabolic heat production, and the magnitudes of the reduction were linear functions of the power density above the threshold values.

This investigator also exposed squirrel monkeys to RFR in ambient temperatures ranging from about 90 to 95 deg F. After an initial 90-min or longer equilibration period, each monkey was exposed for 10-min periods to power densities in an increasing sequence from 2.5 to 20 mW/cm^2, with sufficient time between exposures for reequilibration. The results indicate that at ambient temperatures below about 97 deg F, at which sweating in a sedentary monkey may occur spontaneously, the threshold power density (or SAR) for initiating thermoregulatory sweating decreased with decreasing ambient temperature.

In summary, although some of the effects of RFR exposure on the endocrine system appear to be relatively straightforward and predictable from physiological considerations, other, more subtle effects require further study, notably those related to the interactions among the pituitary, adrenal, thyroid, and hypothalamus glands and/or their secretions. Part of the problem in interpreting results appears to arise from uncertainties regarding stress mechanisms and accommodations thereto. Animals that are placed in novel situations are much more prone to exhibit stress responses than animals that have been adapted to the

situation. However, there may be large variations in adaptation among animals in a given situation or among experimental situations in different laboratories.

In conclusion, because the reported effects of RFR on the endocrine systems of animals are largely ascribable to increased thermal burdens or stresses engendered by the experimental situation, or both, there is no evidence that such effects would occur in humans exposed to the RFR from SEPP outside the exclusion fence.

4.1.1.2.6.8 Immunological Effects. Reports accumulated to date indicate that RFR has definite effects on the immune system of mammals. Most of the reported effects were detected after exposure at power density levels of about 10 mW/cm^2 and higher; a few were detected following exposure to power densities as low as about 0.5 mW/cm^2; and in some cases, effects obtainable with the higher power-density range were not found at lower power densities. In most studies, the mechanisms for the effects seen were not investigated, and the various reports are somewhat inconsistent. Because of the complexity of the immune system and the variety of test procedures used, the representative studies discussed in this subsection are grouped into appropriate categories.

4.1.1.2.6.8.1 In Vitro Studies. An important question is whether human or animal lymphocytes (a type of white blood cell of key importance in the immune system) can be stimulated by RFR exposure to transform into lymphoblasts (mitotically active form of lymphocytes) and undergo cell division (mitosis). In vitro studies directed toward this question are those in which lymphocytes are removed from the body, cultured, exposed to RFR (or exposed, then cultured), and examined for RFR-induced effects. Usually such cells are cultured in the presence of a mitogen (an agent, usually chemical) that stimulates blastic transformation (i.e., lymphocyte to lymphoblast) and cell division.

One of the early investigators cultured specimens of human lymphocytes, added the mitogen phytohemagglutinin (PHA) to one set of specimens, and exposed groups from both sets to 2.95-GHz pulsed RFR at an average power density of either 7 or 20 mW/cm^2 for various durations. The results for the PHA-stimulated cultures showed no significant changes in percentages of blastoid forms, but there were significant decreases in percentages of lymphocytes and increases in the mitotic index correlated with exposure duration. However, another investigator endeavored to repeat these experiments with human lymphocytes, but encountered difficulties in obtaining reproducible results. He implicated uncontrolled temperature increases in the specimens (which were not cooled during exposure) as the problem.

In a representative recent study, bone marrow cells from mice were prepared and exposed at constant temperature to 2.45-GHz RFR for 15 min at 30 to 1000 mW/cm^2 (SARs of 60 to 2000 W/kg). Similar specimens were sham-exposed. Cell samples were then treated with a colony-stimulating factor, permitted to grow in an appropriate medium, and examined on days 5-7 and 12-14 following exposure. No significant

differences were found at either time between the number of colonies from sham-exposed samples and from the samples exposed at 30 mW/cm^2 (SAR of 60 W/kg). However, at higher power densities, the ratio of the number of colonies from RFR-exposed to sham-exposed samples was found to decrease with increasing power density.

In another investigation, bone-marrow specimens from children with acute leukemia in remission or other disorders were similarly exposed. Again, no significant differences between RFR- and sham-exposed specimens were obtained at 31 and 62 mW/cm^2 (SARs of 62 and 124 W/kg). Thus, negative results are obtained when the temperature of the cell suspension is held constant (at 37 deg C) during RFR exposure.

4.1.1.2.6.8.2 In Vivo Studies: Acute Exposures. In most in vivo investigations involving acute (i.e., short-duration) exposures, live animals were exposed one time for a period typically ranging from a few minutes to an hour at power densities high enough to produce substantial temperature increases in various tissues or organs or of the body as a whole. In general, the effects of such acute RFR exposure on the immune system appear to be stimulatory. The number of circulating lymphocytes in the blood increases, as does the ability of the immune system to manufacture antibodies to foreign substances. The number of cells involved in production of immune complement (a complicated series of interacting chemicals in the blood) also increases. The mechanisms of those effects are not completely understood, but in some cases they may be a secondary result of the stress induced in the animals by the RFR-produced heat or by other stresses, such as from handling.

In a study selected to illustrate the complexity of this topic, mice were exposed to 2.45-GHz RFR for 30 min/day at 5 to 15 mW/cm^2 (SARs of 3.7 to 11 W/kg) for 1 to 17 days, after which the spleens were removed and cells therefrom were cultured for 72 hr with or without one of several mitogens. Tritiated thymidine, a radioactively labeled substance whose uptake is an indication of the DNA synthesis involved in cell proliferation, was added 4 hr before the end of the culturing period. The cells were then harvested and assayed for thymidine uptake. Plots of uptake versus exposure duration showed biphasic or cyclical responses for cells from both mitogen-stimulated and nonstimulated cultures from the RFR-exposed mice. The investigators suggested that such cyclical fluctuations could account for the differences in results from various laboratories. However, similar plots for the sham-exposed mice also showed cyclical fluctuations, evidently resulting from factors other than RFR, such as circadian rhythms and estrus cycle changes in female mice; therefore, it was impossible to ascertain the proliferative effects of RFR per se. In another part of the study, RFR exposure at 15 mW/cm^2 for 5 days (30 min/day) did not diminish the effectiveness of lymphocytes against leukemic cells injected after, or concurrently with, the last exposure.

In a series of investigations, exposure of mice to thermogenic levels of RFR produced increases in the numbers of splenic B-lymphocytes (one of several subclasses). There is also experimental evidence for

the existence of a threshold energy absorption (about 10 J/g) for this effect and for the dependence of the effect on genetic factors.

4.1.1.2.6.8.3 In Vivo Studies: Effects of Chronic Exposures on Immunological Parameters. In many investigations involving chronic (long-term) exposures of animals to RFR, changes in various components of the immune systems of usually healthy animals are sought, under the often tacit assumption that such changes could be detrimental (or perhaps beneficial) to the subjects exposed. Investigations of this kind are discussed next. Other in vivo investigations are directed toward determining whether chronic exposure to RFR actually alters the incidence or severity of diseases imparted to the subjects. Studies of the latter kind are described in the next section.

In a representative early study, exposure of mice to pulsed 2.95-GHz RFR at an average power density of 0.5 mW/cm^2 for 2 hr/day, 6 days/week over 6 weeks was reported to cause general stimulation of the immune system. This effect diminished when the exposure was extended to 12 weeks, suggesting that the mice were adapting to the RFR.

Most of the recent investigations involving chronic exposure showed no significant alterations of the immune system. In one such study, pregnant mice were exposed to 100-MHz CW RFR for 4 hr daily from day 6 of pregnancy to parturition. On birth, several male pups were exposed similarly until age 20-22 days, others until 40-42 days, and the remainder until 97 days. The SARs varied with body mass, ranging from a mean of about 2 W/kg for the pregnant dams to about 3 W/kg for the newborn rats. No significant differences in counts of red blood cells, counts of the various types of white blood cells, or the other standard blood tests were found between blood samples of RFR- and sham-exposed rats taken at ages 22 and 42 days. In addition, stimulation by mitogens produced no significant differences in lymphocyte response. The pups removed at age 22 days were immunized with purified pneumococcal polysaccharide. Blood samples taken 5 days later showed no significant differences in antibody levels of RFR- and sham-exposed rats.

In a current study, rats are being exposed for 22 hr/day over their entire lifetimes to circularly polarized, pulse-modulated 2.45-GHz RFR at peak and average power densities of 125 and 0.5 mW/cm^2, respectively. These exposure values were selected to simulate, by scaling considerations, chronic exposure of humans to 450-MHz RFR at an average power density of 1 mW/cm^2. The latest results (through the twenty-first month) indicate no significant differences between RFR- and sham-exposed rats in immunological parameters.

4.1.1.2.6.8.4 In Vivo Studies: Effects of Chronic Exposures on Health and Disease. Relatively few studies have been conducted to determine whether chronic exposure to RFR alters the resistance to, or the severity of, diseases accidentally acquired or purposely given to animals. Such studies have been difficult to conduct, and reliable, consistent results have been hard to achieve.

In an early study, the investigators observed that mice exposed to 9.3-GHz pulsed RFR at 100 mW/cm^2 average power density for 4.5 min/day over 59 weeks appeared to have more resistance than controls to a pneumonia infection accidentally introduced into the colony; however, this was an incidental observation, not the results of a planned experiment.

Subsequent studies yielded mixed results, some indicating that RFR exposure is beneficial and others that it is detrimental to the animal challenged with specific pathogens. However, the results of both kinds indicate that the effects were essentially due to the heat produced by the RFR.

In a recent study, groups of mice were immunized against *Streptococcus pneumoniae* and then sham-exposed or exposed 2 hr/day for 5 successive days to 9-GHz pulsed RFR at an average power density of 10 mW/cm^2 (calculated SAR of 3.3-4.7 W/kg). Another group injected with saline but not exposed served as controls. On day 6 after immunization (the day after exposure), blood samples were taken for various tests, the mice were challenged with a dose of virulent streptococcus that is normally fatal to 50% of the mice, and the number of deaths per day were noted for 10 days after challenge. The RFR-exposed mice had significantly higher levels of circulating antibodies (about 28%) than the sham-exposed mice, but there were no significant differences between the groups in red and white blood cell counts or other standard blood tests. No antibodies were detected in the saline-injected mice. Ten days after challenge, 25 of the 53 RFR-exposed mice and 27 of the 54 sham-exposed mice had died, a nonsignificant difference. However, the greatest number of deaths in one day in the RFR-exposed group (10) occurred on day 6, whereas 14 of the deaths in the sham-exposed group occurred on day 3. The authors suggest that the RFR caused a greater initial neutralization of the pathogens, but not enough to produce complete recovery. No saline-injected mice survived the challenge.

4.1.1.2.6.8.5 Summary of Immunological Effects. RFR does appear to have effects on the immune system of mammals. Some of the reported effects were obtained at low power-density levels, but most of the studies were performed at relatively high power densities; in some cases effects obtained at high power densities were not found at lower power densities, suggesting the possibility that power density thresholds exist. Some of the results indicate immunosuppressive effects; some indicate immunostimulative effects; and others, both kinds of effects. Also, results from various laboratories obtained under apparently comparable conditions are sometimes contradictory, an indication of the probable presence of uncontrolled factors or subtle differences in the experimental protocols. Based on current findings, it appears that *in vivo* RFR-induced effects on the immune system are dependent to varying degrees on the ages of the experimental subjects, the frequency and average power density of the RFR (or the whole-body SAR resulting therefrom), the exposure duration and perhaps the time of day when the exposures are given, the kind of exposure system used (which affects the internal SAR distributions within the animals), and the kind of endpoint analyses undertaken and when they are performed relative to the completion of exposures.

Reported *in vivo* effects on the immune systems of animals from chronic exposure to RFR at average power densities below 1 mW/cm^2 are unlikely to be linked simply to temperature increases, but such results have not yet been replicated elsewhere. In most other *in vivo* investigations, such as those discussed herein, the exposures were at average power densities exceeding 1 mW/cm^2. The existing evidence indicates that some of the immune-system effects are probably mediated through the effect of RFR on the endocrine system, involving the general syndrome of adaptation to stress. The mechanisms and significance of such effects are not yet understood, nor have individual findings been independently verified. There is currently no evidence that reported RFR effects on the immune systems of animals would occur in humans chronically exposed to the levels of RFR from SEPP outside the exclusion fence, or that such effects would be hazardous to human health.

4.1.1.2.6.9 Biochemical and Physiological Effects. The literature on biochemical and physiological effects associated with RFR is extensive. Many of the reported effects are associated with other events (e.g., changes in hormonal levels or stress adaptation), some are questionable for various reasons, and others do not have a clear medical significance.

4.1.1.2.6.9.1 In Vivo Exposure of Intact Animals. In the first of four studies with rhesus monkeys, 12 monkeys were exposed to 10.5- or 26.6-MHz pulsed RFR for 1 hr at average power densities of 200 or 105 mW/cm^2, respectively, or to 19.3-MHz RFR for 14 days, 4 hr/day, at 115 mW/cm^2. Hematologic and blood-chemistry analyses indicated no statistically significant differences between exposed and control monkeys that could be ascribed to RFR. In another part of this study, exposure at increasing power densities up to 600 mW/cm^2 yielded no obvious indications of thermal stress, increases of heart rate, or other influences on the electrical events of the heart cycle due to the RFR.

In the second study, male rhesus monkeys were exposed to 26-MHz CW RFR at 500, 750, or 1,000 mW/cm^2 for 6 hr. Measurements of skin and rectal temperatures indicated that even at the highest power density, the monkeys were in thermal equilibrium; i.e., they were able to dissipate the additional heat induced by the RFR, and their thermoregulatory mechanisms were quite efficient in doing so. Calculations by the investigators show that exposure of a 3.6-kg (about 7-lb) monkey to 26-MHz RFR at 1,000 mW/cm^2 is approximately equivalent to exposing a human 1.8 m (5 ft 11 in.) tall to this frequency at 400 mW/cm^2. The third study, performed at 15 and 20 MHz and power densities ranging from 760 to 1,270 mW/cm^2, yielded similar results.

The fourth was a follow-up study of 18 rhesus monkeys that had been exposed 1 to 2 years previously to 15-, 20-, or 26-MHz RFR for up to 6 hr on at least two occasions at power densities in the 500- to 1,270-mW/cm^2 range. Hematological and biochemical blood parameters were measured, and physical (including ophthalmologic) examinations were performed. No variations from normal values or conditions that could be attributed to RFR exposure were found.

In another primate study, the thermoregulatory system of the squirrel monkey, when stimulated by exposure to increasing levels of 2.45-GHz RFR, was shown to be quite effective in adjusting to the additional thermal burden or to decreases in environmental temperature.

Numerous studies have been performed on the physiological and biochemical effects of RFR in mice, rats, and rabbits. Among the effects reported were increases in oxygen-consumption rate, reduced food intake and blood glucose level, and other changes in blood chemistry indicative of thermal stress. In addition, stress-induced behavioral changes were observed.

In a representative study, mice were exposed to 2.45-GHz RFR under controlled environmental conditions for 30 min, during which the oxygen-consumption rate (a measure of the specific metabolic rate, SMR) and the SAR were determined at 5-min intervals. At the highest power used, the mean SAR decreased, during exposure, from 56 to 39 W/kg while the mean SMR decreased from 17.5 to 14 W/kg, thereby decreasing the mean total thermal burden from about 74 to 54 W/kg. Apparently, the mice endeavored to decrease their thermal burdens by altering their body configurations to minimize their RFR absorption rates.

In another investigation, rats were exposed to 918-MHz CW RFR at 10 mW/cm^2 (mean SAR of 3.6 W/kg) for 10 hr/day over 3 weeks. Physiological and behavioral comparisons between RFR- and sham-exposed rats showed no significant differences in fluid intake, body weight, rectal temperature, and corticosterone levels. However, food intake and blood glucose level were lower for the RFR-exposed animals, and their behavioral repertoires were altered, apparently to cope with the additional thermal burden imposed by the RFR. Two other similar investigations confirmed these findings, which indicate the existence of an SAR threshold between 0.9 and 3.6 W/kg for such effects. In consonance with this threshold are the results of another investigation in which mice were exposed to 148-MHz RFR at 0.5 mW/cm^2 (mean SAR of 0.013 W/kg) for 1 hr/day, 5 days/week for 10 weeks. Blood samples drawn at ages 28 through 600 days of age showed that the formed elements in the blood were not affected.

Another physiological effect reported was bradycardia (lower heart rate) in rats exposed to 2.45-GHz RFR for 30 min at relatively high SARs. Specifically, statistically insignificant bradycardia was observed in rats exposed at 4.5 W/kg; mild but statistically significant bradycardia developed within 20 min for those at 6.5 W/kg, with recovery within about 2 hr; and pronounced bradycardia developed abruptly for those exposed at 11.1 W/kg, after which heart rates increased to values well above those of controls (tachycardia) and persisted at these levels to the end of the test period. These effects were evidently due to the excessive heat from the RFR.

None of these effects in intact live animals would be likely to occur in humans exposed to the RFR levels from SEPP outside the exclusion fence.

4.1.1.2.6.9.2 In Vivo and In-Vitro Exposure of Specific Tissues. Studies have been conducted to determine the physiological effects of RFR on various tissues either excised completely and kept alive artificially or accessed surgically and locally exposed in the live animal, with mixed and sometimes contradictory results.

One group of investigators reported that the contraction rate of excised segments of rat gut could be altered by exposure to 960-MHz RFR for 10 min at SARs of 1.5 to 5.5 W/kg. However, a similar study by another group did not confirm this finding.

Alterations of heart beat rate in excised turtle and frog hearts by exposure to RFR were observed by several investigators, but at either measurable heart temperature increases (e.g., 0.2 deg C) or heart SARs of 1.5 W/kg and higher. Another group of investigators surgically induced myocardial ischemia (inadequate blood flow rate to the heart) in the live cat and exposed the heart to 2.45-GHz CW RFR for 5 hr at an SAR of 30 W/kg. Although physiological differences between ischemic and nonischemic cats were evident, RFR exposure produced no significant changes in either group in mean arterial blood pressure, cardiac output, heart rate, EKG, or several subsequent heart tissue assays. These results indicate that local exposure of either the undamaged or ischemic heart to CW RFR in vivo at SARs as high as 30 W/kg has no effect on the myocardium or its neural components. These investigators also exposed isolated atria of spontaneously beating rat hearts for 30 min to 2.45-GHz CW RFR at 2 or 10 W/kg. Measurements of contractile force and beat rate showed no significant differences between RFR- and sham-exposed specimens. All of these findings are at variance with those obtained from isolated turtle and frog hearts.

In 1968, exposure of isolated frog hearts to 1.425-GHz RFR pulses triggered synchronously with the EKG (200 ms after the peak of the R wave) was reported to produce significant tachycardia. However, in two subsequent studies by other investigators, this effect was not reproduced.

4.1.1.1.6.9.3 In Vitro Cellular Effects. The principal technical problems in studying effects of RFR on cells in various media arise because such investigations are often conducted using conventional apparatus designed for cell studies--flasks, dishes, holders, agitators, water baths, incubators, and the like--and various elements of the apparatus may distort the field in such a way that the SARs of the cell cultures may be severalfold higher or lower than field measurements indicate. Thus, the results of many investigations on RFR-induced effects on cell and tissue cultures are questionable. However, progress has been made in designing exposure apparatus for cell cultures that provide for accurate measurements of SAR in such cultures.

In 1974, researchers reported increases in membrane permeability of rabbit erythrocytes (red blood cells) and granulocytes (a type of blood cell that contains granules in its cytoplasm) during in vitro exposure for up to 3 hr to 1-GHz RFR at power densities of 1 to 10 mW/cm^2.

Other investigators subsequently showed that membrane permeability increases from RFR exposure were thermally induced. For example, suspensions of rabbit, human, and dog erythrocytes were exposed for 3 hr to 2.45-, 3.0-, or 3.95-GHz RFR at various SARs; the resulting suspension temperatures ranged from 25 to 44 deg C. The investigators also heated such cell suspensions in a water bath to comparable temperatures. As a representative result, they found no significant differences in membrane permeability between RFR-exposed suspensions and those heated to the same temperature. Researchers also found no significant differences in the sequence and time course of mouse fibroblast cells heated to 43 deg C by RFR or water bath.

Exposure of Escherichia coli B bacterial cells in aqueous suspension to 2.6- to 4.0-GHz RFR for 10 hr at an SAR of 20 W/kg had no significant effect on their colony-forming ability or molecular structure.

4.1.1.2.6.9.4 Conclusions Regarding Biochemical and Physiological Effects. The thermal basis for most of the reported physiological and biochemical effects of *in vivo* exposure of intact animals to RFR is evident. Most significant with respect to possible hazards of human exposure to RFR are the investigations with nonhuman primates because their anatomies and physiological characteristics are closer to those of humans than are those of other experimental animals. The results with rhesus monkeys showed that exposure to RFR at frequencies in the HF range at average power densities of the order of 100 mW/cm^2 were well within the thermoregulatory capabilities of this species. Also noteworthy were the negative findings of the blood-chemistry assays performed on rhesus monkeys 1-2 yr after exposures to such high power densities and the observations that the thermoregulatory system of the squirrel monkey is quite effective in compensating for RFR exposure.

The investigations involving exposure of intact, smaller species of mammals to RFR have yielded a variety of positive and negative results. Some of the positive findings are also clearly due to the additional thermal burden imposed by the RFR. Other results, such as those on decreased food intake and lower blood glucose levels in rats, indicate the existence of an SAR threshold of about 1 W/kg or higher for such effects.

One physiological aspect of concern is whether exposure of humans to RFR can affect their heart function. In early work on this subject with excised turtle, frog, or rat hearts, various investigators reported RFR-induced bradycardia, tachycardia, or both (depending on average power densities, with bradycardia for the lower range of power densities used). The lowest SAR at which bradycardia was observed in the isolated turtle heart was 1.5 W/kg. More recently, no RFR-induced changes were found in beat rate or contractile force in isolated atria of rat hearts exposed to 2.45-GHz CW RFR at 2 or 10 W/kg.

The possibility that pulsed RFR at pulse rates that are synchronous with various periodic characteristics of the EKG may alter the heart rate was also investigated. Significant tachycardia in isolated

frog hearts induced by pulsed RFR was reported in 1968. However, subsequent investigators were unable to reproduce this effect.

SAR-dependent changes in heart beat rate in intact animals were also reported. The results indicate the existence of a threshold between 4.5 and 6.5 W/kg.

Investigators found no significant changes in the mean arterial blood pressure, heart rate, and colonic temperature of unanesthetized rats exposed to CW RFR at 10 mW/cm^2 and no differences in various blood-chemistry parameters. These investigators also compared the results of in situ RFR exposure of the cat heart with and without myocardial ischemia, and found no significant differences ascribable to the RFR, an indication that RFR at the levels used does not affect the functioning of already damaged hearts.

The preponderance of results indicates that pulsed RFR synchronized with elements of the EKG does not alter the heart beat rate. Some of the results indicate that CW RFR does not alter heart function, and others that it does. However, most of the results, both positive and negative, support the conclusion that the effects occur at relatively high average power densities (above 1 mW/cm^2) or SAR values (above 1 W/kg). The same conclusion is applicable to the in vitro cellular effects discussed in the previous section, which were obtained at much higher SARs than those in the tissue preparations. Thus, the occurrence of physiological or biochemical effects from exposure to the RFR from SEPP at the levels outside the exclusion fence is very improbable.

4.1.1.2.7 Misconceptions. Several misconceptions regarding the bioeffects of RFR continue to be expressed in popular accounts outside peer-reviewed scientific publications on the subject. Those accounts tend to be sources of some confusion for the nonspecialist. The following are representative examples.

The distinction between RFR and ionizing radiation is often not made; consequently, the known hazards of ionizing radiation are linked--by implication--with exposure to RFR. In essence, ionizing radiation (which includes ultraviolet light, X-rays, and the emissions from radioactive materials) has sufficient quantum energy (see Section 4.1.1.2.5.1) to expel an electron from a molecule, leaving the molecule positively charged and thereby strongly affecting its interactions with neighboring molecules. Ionization can alter the functions of biological molecules fundamentally and often irreversibly.

By contrast, the quantum energies of RFR are so much smaller that their primary effect is to agitate molecules rather than to ionize them. (The possibility of long-range quantum interactions, discussed in Section 4.1.1.2.5.1.3, is not excluded; however, evidence of their occurrence in live animals is sparse as yet, and there is no evidence that such effects would be harmful if they do occur.) Also, RFR-induced agitation ceases as soon as exposure to RFR is halted. At low RFR intensities, the heat that such agitation represents is well accommodated by the

normal thermoregulatory capabilities of the biological entity exposed, and therefore such effects are generally reversible. At high RFR intensities, the thermoregulatory capabilities may be inadequate to compensate for such effects, and exposure at such intensities may lead to thermal distress or even irreversible thermal damage. In short, a single quantum of ionizing radiation that is absorbed by a molecule alters the properties of that molecule, and exposure to such radiation may thereby profoundly affect the function of the biological constituent involved, whereas the concurrent absorption of many quanta of RFR is necessary to cause biologically significant effects.

Even if an effect is produced by RFR, that effect may not necessarily be deleterious to the entity involved. As an example of a nonhazardous biological effect, the eyes must absorb light (a form of electromagnetic radiation having quantum energies above those of RFR but below those of the ionizing radiations mentioned previously) for vision. Light is also absorbed by the skin and at normal levels is converted into harmless heat. One of the reasons that the levels of allowable human exposure to RFR are generally lower in Eastern European countries than they are in the West is the philosophically based assumption that even small RFR-induced effects are potentially harmful--a view not generally shared in Western countries.

Concerned people often ask whether guarantees can be offered that chronic exposure to low levels of an agent such as RFR will have no deleterious effects many years in the future. It is scientifically impossible to obtain data on which a guarantee of absolute safety can be based. However, the large body of experimental data on the bioeffects of RFR indicates that, unlike the ingestion of certain substances in small quantities that can accumulate into a potentially harmful dose, RFR energy continually absorbed at low incident power densities (dose rates) is readily dissipated and does not accumulate in the body toward the equivalent of RFR energy absorbed at high incident power densities. This is one of the basic reasons for the existence of threshold power densities for the various RFR bioeffects.

4.1.1.2.8 Unresolved Issues. The potential biological effects of RFR have been assessed from existing studies at frequencies up to 300 GHz. Based on the studies evaluated, with recognition that the negative findings reported in some studies may have been obtained because the experiments had been poorly conducted, there is no reliable evidence to indicate that chronic exposure to RFR at incident average power densities below 1 mW/cm^2 or at SARs below 0.4 W/kg is likely to be hazardous to human health. However, certain gaps remain in our knowledge of the biological effects of RFR. These gaps may be identified as follows:

(1) Epidemiologic Studies. Epidemiologic studies of effects of human exposure to RFR, in which the actual frequencies, levels, and durations of exposure are accurately known and quantified, are lacking. Existing epidemiologic studies, while extensive and reasonably well done, are subject to inherent defects, such as unavailability of complete sets of

medical records, death certificates, or health questionnaires, or imprecise classification of the individuals with regard to RFR exposure.

(2) Extrapolation of Findings on Animals to Humans. The most directly applicable experimental evidence relative to possible bioeffects of exposure to the RFR from any specific system such as SEPP would be from studies in which humans were exposed to the frequencies and waveform characteristics of that kind of system for appropriate durations at the pulse and average power densities likely to be encountered. Further, quantitative evaluation of many biological endpoints would be necessary. Such data, of course, do not exist. Instead, data are obtained from laboratory animals (mostly small rodents) used as surrogates for humans, a standard practice for investigating the effects of other agents. Because of the biological differences among species, a basic uncertainty in this practice is its degree of validity, which depends in part on the species used, the nature of the agent and its quantitative aspects, and the biological endpoints studied. In investigations of RFR bioeffects, much progress has been achieved in quantifying exposures in terms of whole-body SARs and internal SAR distributions in animal carcasses and in physical and mathematical models of various species (including humans). For example, such data can be used to determine what the whole-body SARs would be in humans at a frequency in the 420-450 MHz range, if, say, laboratory rats are exposed to 2.45-GHz RFR at prespecified power densities. Nevertheless, there are significant gaps in knowledge regarding internal SAR distributions in humans. Moreover, most such interspecies calculations do not endeavor to account for the roles of blood flow and other factors in determining heat flow patterns or of thermoregulatory mechanisms in mammals that maintain constant body temperatures.

(3) Thresholds and Long-Term, Low-Level Studies. Most experimental data indicating the existence of threshold power densities for various RFR bioeffects were obtained from exposures for relatively short durations. Although it is difficult to conceive of mechanisms whereby RFR exposures at well below threshold values over a long time could result in cumulative effects deleterious to health, there have been very few investigations involving exposure of animals to low-level RFR over a large fraction of their lifetime.

(4) Differential Bioeffects of Pulsed Versus CW RFR. Questions of quantitative and/or qualitative differences in bioeffects induced by pulsed versus CW RFR at equivalent average power densities cannot be resolved fully from current knowledge (i.e., some investigators have found no significant differences, whereas others have). Also, it should be noted that although the permissible average power densities in most

current and proposed safety guidelines are applicable to both pulsed and CW RFR, these guidelines do not include maximum allowable pulse power densities per se.

In the light of these gaps, the possibility that new information would reveal a significant hazard from chronic exposure to low levels of RFR cannot be dismissed, but is judged to be relatively low.

4.1.1.2.9 Conclusions. Collectively, the results of the relatively few epidemiologic studies performed in the United States, the USSR, and other Eastern European countries are not regarded as evidence that environmental levels of RFR are likely to constitute a hazard to the general population.

Most U.S. experiments with animals that yielded recognizable and repeatable effects of exposure to RFR were performed at incident average power densities of more than about 2 mW/cm^2. Such effects are thermal in the sense that the RFR energy is absorbed by the organism as widely distributed heat that increases the whole-body temperature or as internally localized heat that is biologically significant even with natural heat-exchange and thermoregulatory mechanisms operating. The existence of threshold average power densities has been experimentally demonstrated for some effects and postulated for the others. Exposure to RFR at average power densities exceeding the threshold for a specific effect for a few minutes to a few hours (depending on the value) can cause irreversible tissue alterations. The heat produced by indefinitely long or chronic exposures at power densities well below the threshold is not accumulated because its rate of production is readily compensated for by heat-exchange processes or thermoregulation. Most investigations involving chronic exposures of mammals yielded either no effects or reversible, noncumulative behavioral or physiological effects for average power densities exceeding 2 mW/cm^2. In the few cases in which irreversible adverse effects of exposure were found, such effects were absent for average power densities below 2 mW/cm^2.

In a relatively small number of investigations, biological effects of RFR were reported at incident average power densities less than about 2 mW/cm^2. Such effects have been called "nonthermal," to distinguish them from those considered above. However, this usage of "nonthermal" is confusing and imprecise because the interaction mechanisms involved in each such effect differ considerably from those for the other effects, and clear distinctions between "thermal" and "nonthermal" based on precise scientific definitions of these terms are difficult to discern in the interactions.

Alterations of the blood-brain barrier that permit entry of normally blocked substances into brain tissue from its blood vessels have been reported for pulsed and CW RFR at average power densities as low as 0.03 mW/cm^2, but the effects at such low levels appear to be artifactual. Results of a subsequent study at 15 mW/cm^2 indicate that the technique used does not permit discrimination between changes in local cerebral blood flow and small alterations of the blood-brain barrier.

Most experimental results indicate that significant localized heating of brain tissue is necessary to produce the effect.

The calcium-efflux phenomenon in brain-tissue preparations exposed to VHF or UHF RFR modulated at sub-ELF frequencies has been ascribed to complex, long-range quantum interactions, and such interactions are basically nonthermal. Most of the experiments to date were performed in vitro, with mixed results. Some of these results indicate that the phenomenon may occur in narrow amplitude "windows" for specific modulation frequencies, which may account in part for contradictory findings. However, very few experiments have been performed in vivo thus far.

One pulse power effect known to occur in humans is the detection of individual RFR pulses as apparent sound. This phenomenon has been characterized as nonthermal, primarily on the basis that the average power density would be minuscule if the time intervals between consecutive pulses were large. However, the average power density is not relevant, because the interactions that produce the effect are dependent primarily on the characteristics of individual pulses. For perception, a pulse-power-density threshold of about 300 mW/cm^2 must be exceeded. No ill effects from this phenomenon have been reported, and human volunteers have been exposed to pulse power densities as high as 2,000 mW/cm^2 (i.e., well above the 900 mW/cm^2 maximum pulse power density of SEPP) without apparent harm.

In summary, the review of the relevant literature indicates that there is no reliable scientific evidence to suggest that chronic exposure to the RFR from SEPP outside the exclusion fence is likely to be deleterious to the health of even the most susceptible members of the population, such as the unborn, infirm, or aged.

4.1.1.2.10 Other Viewpoints. Some of the general concerns expressed following review of the Draft Environmental Impact Statements for the Otis ANG Base and Beale AFB PAVE PAWS installations were as follows: First, data on which to base an assessment of potential hazard to human health are insufficient; second, research on the effects of long-term, low-level exposures is only in its infancy; third, because little is currently known about the details of mechanisms of interaction of RFR with biological tissues, potentially hazardous effects that may occur have not been more precisely targeted for study; fourth, certain studies report effects at average power densities less than 0.1 mW/cm^2; fifth, even though some studies report negative findings (i.e., no effects as a result of RFR exposure), such negative findings can possibly be attributed to faulty experimental design or procedures; sixth, epidemiologic studies from the Soviet Union have reported various symptoms in persons exposed for many years to RFR at levels in the range from tenths to hundredths of a mW/cm^2--symptoms that when taken together are called the "microwave radiation syndrome"--but that such symptoms are not recognized in Western epidemiologic studies; seventh, although we know much more today than we did 10 years ago, we will know even more 10 years from now and it is therefore likely that with this additional knowledge will come recognition of new, hazardous effects of long-term,

low-level exposure to RFR; eighth, safe power thresholds for RFR exposure of the general population have not been established, and, further, safety standards vary from country to country; and ninth, research on possible alterations of genetic material and carcinogenic effects of long-term, low-level exposure to RFR has been insufficient.

Commenters have presented the following documentary evidence as reasons for these concerns: The studies by Bawin and Adey on calcium efflux changes; the studies by Frey on blood-brain barrier permeability changes and modifications of behavior, the studies by Shandala on changes in the immune system; the studies by Oscar and Hawkins on changes in permeability of the blood-brain barrier to certain radiotracer-labelled molecules. The studies by these investigators and others on the same topics are summarized herein and are referenced and discussed in more detail in the RFR-bioeffects review. They do not alter the conclusion that there is no reliable evidence that the low levels of exposure to RFR from SEPP will be hazardous to the general public. The study completed by the National Academy of Sciences for the Otis ANG Base PAVE PAWS supports this conclusion because the calculated ground-level average power densities from SEPP outside the exclusion fence are comparable to or less than those outside the exclusion fence of the Otis system.

4.1.1.3 Electromagnetic Environment

4.1.1.3.1 The Addition to the Environment. Operation of PAVE PAWS changes the electromagnetic environment for the duration of its pulses within the physical space its pulses reach and generally over the frequency bands of its operation. (Appendix C presents a detailed analysis of the change.) This change can be described both as an actual addition of electromagnetic energy to the electromagnetic environment and in terms of how that energy affects other systems and thus becomes perceptible to those using the systems.

Civilian use of the radio spectrum is under the control of the FCC; government use is under the control of the National Telecommunications and Information Administration (NTIA), formerly the Office of Telecommunications Policy (OTP). Because PAVE PAWS is a military system, a detailed application for spectrum support was made through Air Force channels to the Interdepartment Radio Advisory Committee (IRAC) of the NTIA, which subsequently authorized operation of the radar.

SEPP would transmit pulses in the band from 420 to 450 MHz, which is within what is commonly called the UHF (ultra-high frequency) band. The band is shared with various other government radars, with radar altimeters in aircraft, and with the Amateur Radio Service, which currently has a satellite relay in orbit. The band immediately below that of PAVE PAWS (406 to 420 MHz) is used exclusively by the federal government for both fixed links and mobile services. Users of the band immediately above (450 to 470 MHz) include public safety groups (police, fire, forestry, highway, and emergency services), industries (power, petroleum, pipeline, forest products, and so forth), and providers of

land transportation (taxis, railroads, buses, trucks). They commonly use repeaters on tall towers or buildings to increase their areas of coverage. The UHF TV channels--channels 14 through 83--are in the band from 470 to 890 MHz.

Each of the two faces of SEPP is essentially an independent radar system. Each face transmits a narrow beam of energy; within a few tens of millionths of a second, the beam is switched electronically to another direction. Each face of the radar can form beams over an azimuthal angle of 120 deg, so that the radar can observe in a 240-deg azimuthal sector from 10 deg to 250 deg.

SEPP will generally search for objects rising through the surveillance volume (which is usually at an elevation angle of 3 deg, but is sometimes higher), but some time is used for tracking objects previously found. When searching, it will transmit closely spaced clusters of pulses--a pair of 8-ms pulses, a triplet of 5-ms pulses, or a sequence of triplets of 0.3-ms pulses. The PAVE PAWS computer selects the pulse widths for tracking on the basis of the distance to the target, the target trajectory, and the like. When searching, the beams from the two faces move in synchronism; that is, the beam motions of one face are duplicated by the beam motions of the other face. When tracking, the beam from each face is independent.

PAVE PAWS has 24 evenly spaced frequency channels (between 420 and 450 MHz), and it changes frequency for each succeeding pulse according to rules programmed into the system's computers for dealing with the actions of any targets being tracked. It generally changes frequency by at least 3.6 MHz from pulse to pulse.

The pulse and frequency-switching behavior of SEPP cannot be predicted exactly because, although controlled by rules programmed into the computer, the behavior depends on the number and orbital characteristics of the objects it is called on to track. Only average characteristics of SEPP emissions can be predicted.

SEPP will point its main beam at an angle in the range from 3 to 85 deg above the horizon. Not all the power is in the main beam, however. Much smaller concentrations of power also exist in the sidelobes. The respective maxima of the first and second sidelobes are about 2.1 deg and about 3.4 deg off the main-beam axis. Relative to the maximum power density of the main beam, the maximum power density of the first sidelobe is 1/40 or less, and that of the second sidelobe is 1/77 or less. SEPP also has many minor concentrations of power in higher order sidelobes, at increasingly greater angles off the main-beam axis. The power density of the greatest of these is 1/1,000 or less of the main-beam power density, and most are much weaker.

The main beam does not illuminate the ground, and the radar is not used to track aircraft. However, an aircraft flying within the surveillance volume is illuminated by some sort of main-beam surveillance pulse about once every 1.7 s and by the first sidelobe about twice as

often. In the much larger tracking volume, illumination by the main beam occurs only about once in 35 s as a rough average. In the volume scanned, as well as outside it, the aircraft is illuminated by the higher order sidelobes. The higher order sidelobes extend in all directions in the hemisphere centered on each face, so an object illuminated by them receives a signal on each pulse--surveillance and tracking. Objects on or near the ground are illuminated primarily by the second and higher order sidelobes.

4.1.1.3.2 The Effects of SEPP on Systems. SEPP's contribution to the electromagnetic environment could possibly affect systems also using the electromagnetic environment as well as systems not intended to receive electromagnetic energy. Other users of the spectrum include TV, radio, and other radars; systems or processes not intended to receive electromagnetic energy include cardiac pacemakers, electroexplosive devices, and fuel-handling processes.

In the calculations and predictions of interference presented in Appendix C and summarized here, many of the terms and factors had to be assumed. Medians and averages were often used, but conditions under specific circumstances can deviate considerably from the average. The effects of interference on various receiver systems were evaluated subjectively on the basis of engineering judgment; only interference tests could resolve some of the uncertainties.

4.1.1.3.2.1 Effects on Telecommunication, Radionavigation, and Radiolocation Systems. Although two types of military aircraft radar altimeters share the spectrum with SEPP, their operation is to be discontinued eventually. The OTP and its successor, NTIA, have extended the cutoff date several times already. (These altimeters supplement the required barometric altimeter, which is unaffected by a PAVE PAWS radar.) Neither type of altimeter is used for landing approaches, and one is not to be used within 50 miles of land (i.e., within about 210 miles of Robins AFB or within 130 miles of Moody AFB). Many land-based radars interfere with these radar altimeters. Study indicates that both types are affected when they are in radio line of sight of a PAVE PAWS. The altimeter used only over the sea would be in line of sight of PAVE PAWS at Robins AFB only if the aircraft were over the nearest part of the ocean and above about 20,000 ft; thus, low-altitude use would not be affected. An aircraft over the Gulf of Mexico could be in line of sight of a PAVE PAWS at Moody AFB only if it were above about 7,200 ft. Even when this overwater altimeter is illuminated by PAVE PAWS, however, it may continue to provide useful altitude information. Use of the other altimeter is not known to be limited to overwater flight, but its maximum altitude is only 4,000 ft, limiting the area in which it may be illuminated by PAVE PAWS. If an aircraft that low is flying over the ocean, the curvature of the earth shields it from SEPP.

The Amateur Radio Service (the Hams) shares the entire 420- to 450-MHz band with PAVE PAWS and the other radar systems. Although the Amateur Service is the primary service in other bands, it is a secondary service in this band, permitted to operate but not to interfere with the

operation of any government radar or to claim protection from interference caused by government radars. In the upper 10 MHz of the band, the Hams' mobile operations are often augmented by the use of strategically placed repeaters, but none were listed for Georgia in the latest Ham's Repeater Directory. In addition to fixed and mobile systems, the amateurs currently operate an orbiting satellite transponder and conduct moon-bounce communications. The satellite transmits on 435 MHz. Interference with the satellite or with moon-bounce is possible when the satellite (or the moon) is above the horizon. Interference could be alleviated, operational requirements permitting, if SEPP discontinued its use of those two frequencies when the satellite (or the moon) were in sight.

The bands immediately adjacent to PAVE PAWS are used for UHF land mobile communications. Below PAVE PAWS, from 406 to 420 MHz, is the federal government's UHF land mobile band used by the Federal Aviation Administration, the Department of the Interior, the military services, and others. Above PAVE PAWS, from 450 to 470 MHz, is the nonfederal government UHF land mobile band, which is used by local governments and by businesses. The same equipment (narrow-band FM voice transceivers) is used in both bands. The numbers of UHF land mobile base stations and repeaters operating within about 50 miles of the candidate SEPP sites at Robins and Moody AFBs are more than 600 and about 400, respectively. Some of them, located high to increase their own coverage area, might be directly in the line of sight of the radar. SEPP signals would enter those receivers at strengths that would depend on the distance between the radar and the receiver, the frequency offset between an individual SEPP pulse and the receiver's center frequency, the type of transmitted pulse, the antenna lobe that illuminates the receiver, and the characteristics of the receiving facility. When a receiver is not receiving a desired signal, its squelch circuit keeps the audio portion of the receiver shut off. PAVE PAWS pulses are generally so short that the squelch circuit does not have time to respond during a pulse. Therefore, when there is no desired signal, SEPP would not cause effects perceptible to the listener. When a desired signal holds the squelch circuit open, the PAVE PAWS pulses, which are generally stronger than the desired signal, may be heard as pops and clicks. They would occur at such low pulse rates (several seconds between pulses) that they probably would not disrupt voice communication. No problems have been noted for the numerous repeaters directly in front of the PAVE PAWS radar at Beale AFB in California.

Interference with a system of land mobile repeaters seems likely in one situation. The Georgia Power Company uses three repeaters near Robins AFB, with antennas on a tall tower near a large substation only about 2 miles from and in front of the candidate radar site. Their receiving frequencies are only about 7 MHz from the nearest SEPP channel. The Air Force would aid the Georgia Power Company in resolving any interference problems. Two possible solutions would be to change the Georgia Power Company frequencies to frequencies farther from those of PAVE PAWS or to relocate the tower, placing it behind the radar. Some

testing could be done beforehand, but only experience would indicate for certain whether the interference would be tolerable.

Communications between aircraft and the ground at both Robins and Moody AFBs are handled by UHF/AM systems in the band between 225 and 400 MHz. At the ground station, behind the candidate radar site in both cases, power from PAVE PAWS would be greatly attenuated by the thick foliage and thus would not be expected to interfere with the voice signal from an aircraft. On the basis of some calculations, as well as on the several years of experience at the two existing PAVE PAWS radars, no interference would be expected with communications between the ground and an aircraft.

Interference with various air-navigation systems (besides communications and in-band radar altimeters) has been considered. TACAN and VORTAC stations provide aircraft with range and distance information. Only three VORTAC/DME stations are located within 50 miles of Robins AFB and eight within 50 miles of Moody AFB. They would not be affected by SEPP. The receivers in the aircraft, however, could exhibit a spurious response to one of the SEPP pulses. (The specific pulse frequency depends on the ground station the aircraft is using.) This spurious response would require a very strong SEPP signal, such as could be provided only by the radar's main beam. Such a main-beam pulse on the correct frequency would illuminate the aircraft only about once every 40 s if the aircraft were in the surveillance volume. Because PAVE PAWS does not track aircraft, and because the tracking volume is much larger and receives fewer main-beam pulses, illumination by a main-beam pulse at the correct frequency in the tracking volume would be extremely rare. Even so, those pulses would not affect operation of the airborne DME receiver, which is designed to ignore pulses other than its own downlink pulses returning from the ground station. Tests with the airborne components showed that neither of the two aircraft DME receivers tested was affected at power density levels corresponding to SEPP main-beam illumination at about 8 miles. (This was the maximum power density level available from the testing equipment, so it is possible that no effects would occur at even smaller distances.)

The term "high-power effects" is used to describe the coupling of energy directly into an electronic system through its case or internal wiring. High-power measurements have been conducted on some airborne navigation-system receiver units. Some effects were observed at power density levels corresponding to illumination by the main beam at distances as great as 15 miles. Such effects would depend strongly on the frequency of the interfering PAVE PAWS signal and the strength of the desired signal. High-power effects have been observed in two Army OH-58A helicopters operating about 500 ft above ground about 1.2 miles away from the PAVE PAWS at Otis ANG Base. PAVE PAWS caused false readings in the helicopters' fuel gauges and engine-rpm indicators.

Some laboratory measurements have been made at PAVE PAWS frequencies (but not using PAVE PAWS pulse widths or pulse rates) to determine the interfering signal levels that would affect home high-

fidelity stereo units, AM radios, land mobile transceivers, and so on. Very small samples were used, sometimes only one or two items. These limited tests indicate that effects would be possible for more than 20 miles in front of the radar or 3 miles behind it; the latter includes the base housing area at Robins AFB. Despite similar analysis results for Beale AFB, the PAVE PAWS there has produced no complaints about interference with stereos, transceivers, and the like.

SEPP could possibly interfere with reception of television channel 9 near Robins AFB or 10 near Moody AFB by means of spurious responses that could occur when the radar were transmitting on frequencies in the bands 420 to 425 MHz and 431 to 437 MHz, respectively. The occurrence of this interference would depend not only on the relative strengths of the SEPP signal and the desired channel 9 or 10 signal, but also on the susceptibility of the particular TV set. The signal strengths can be estimated, but the susceptibilities are unknown except in a gross statistical sense. Although research suggests that this interference might be experienced at distances of many miles from the radar, there is no indication that it has been a particular problem near either of the two currently operating PAVE PAWS radars.

TV receivers in the nearest residences, only about 1.5 miles in front of the radar, would be likely to suffer interference caused by either saturation or high-power effects. Interference would be unlikely in Warner Robins or in the base housing, which is behind SEPP.

A high proportion of the TV viewers in the city of Warner Robins and on Robins AFB subscribe to cable TV. Although interference to that system would be unlikely, if an interference problem were to arise, the SEPP signal could be filtered out directly at the cable TV system's master receivers so that it would not appear on the subscriber's TV set.

The most common form of interference to television that has actually been noted has been saturation of an antenna-mounted wideband preamplifier that some viewers use to receive signals from distant stations. If this form of interference were to be reported in the vicinity of Robins AFB, the Air Force would install, at no charge to the TV owner, a specially developed filter to relieve the interference.

No interference with communication systems such as point-to-point microwave links would be expected to result from the harmonics of the SEPP signal near either Robins or Moody AFB.

4.1.1.3.2.2 Effects on Pacemakers, Electroexplosive Devices, and Fuel Handling. A design susceptibility threshold of 200 V/m (the electric field equivalent to a power density of 10 mW/cm^2) was suggested for cardiac pacemakers in a 1975 draft standard by the Association for the Advancement of Medical Instrumentation. Newer models of cardiac pacemakers have been tested against signals very similar to those radiated by PAVE PAWS, and most are unaffected by pulsed fields as high as 330 V/m. The pulse field at ground level at the 1,000-ft exclusion fence would be lower than 200 V/m at both of the candidate PAVE PAWS

sites. Therefore, an earthbound owner of a pacemaker with a susceptibility threshold of 200 V/m most likely would not be affected by SEPP.

The suggested 200-V/m susceptibility threshold would be exceeded regularly by the SEPP signal only in the main-beam surveillance volume within about 3.5 miles of the radar and at elevations below about 1,200 ft. Generally, this airspace is traversed only by military aircraft, which pass through quickly and are not likely to be carrying passengers or crew with pacemakers. For various reasons, described in Appendix C, illumination of aircraft is not expected to constitute a hazard to pacemaker owners.

Air Force Technical Manual T.O. 31Z-10-4 on electromagnetic radiation hazards instructs that fuel-handling operations (fueling of aircraft and so on) should not be undertaken in electromagnetic fields with pulse power greater than 5,000 mW/cm^2. Fuel-handling operations at both Robins AFB and at Moody AFB would take place more than 3 miles behind SEPP. The SEPP field strengths there are estimated to be a factor of about 25,000,000 lower than the maximum safe power density. The maximum power density that would ever occur near the ground, even directly in front of SEPP at any distance, would still be a factor of about 50 less than the maximum safe level. SEPP would not pose a hazard to fuel-handling operations at either base.

Average power densities at ground level that exceed the no-fire safety criteria for electroexplosive devices (EEDs) could be encountered only within a few hundred feet of the radar. Average power densities would be far below the safe exposure limits at all known locations at Robins and Moody AFBs where EEDs are stored or handled or where aircraft equipped with EEDs might taxi.

The average power-density criterion for aircraft in flight carrying EEDs is 100 W/m^2 (10 mW/cm^2). However, the Air Force standard does not indicate the duration over which the power density should be averaged. If the average is taken over many seconds, aircraft on the flight tracks of Robins and Moody AFBs would never experience average power densities that high. The pulse power density from the long-range surveillance pulse would exceed that level out to about 3.5 miles, however, so an aircraft in the surveillance volume of the radar would be periodically illuminated by such pulses, each of which would last for up to 8 ms. Air Force experts do not believe that this constitutes a hazard.

4.1.1.4 Plants and Animals

Significant effects on plants or animals are not expected to result from the RFR or the operation of SEPP. Temporary effects may occur near the site; for example, the repulsion or attraction of species that are sensitive to noise and other human disturbances associated with radar operation.

4.1.1.4.1 Main Beam Exposure. At its lowest elevation, the main beam from SEPP is pointed at 3 deg above the horizontal; no part of it ever strikes the ground. The first-order sidelobe strikes elevated ground in a few isolated locations, but does not contribute substantially to average power densities, which are typically below 0.01 mW/cm^2. The average power density is even lower at most locations.

The biota that could be potentially affected by the main beam are airborne fauna, such as birds and possibly bats and high-flying insects.

Of ecological interest are the birds that might be exposed to RFR, particularly at maximum average power densities at altitudes that correspond to 3-deg elevation. At this elevation, the average power density as given by equation 3 from Appendix B is $U_4 = 5.0 \times 10^6/R^2$. It reaches the value of about 1.5 mW/cm^2 at a distance of 1,850 ft, where the beam altitude is about 152 ft. However, in the overlap region, the value is about double, or 3 mW/cm^2. As discussed in Section 4.1.1.2, the RFR-bioeffects literature suggests that biological effects, not necessarily hazardous, are possible at average power densities exceeding 1 mW/cm^2. Thus, the only potential area of concern about near-field exposure consists of those few airborne organisms flying between about 300 ft and 600 ft elevation in the 240-deg span of surveillance, and less than 1,850 ft from the radar. The maximum exposure duration would be but a few minutes for transient organisms that traverse this area. During enhanced tracking at 25% duty cycle, airborne fauna directly in front of either face of the radar in the middle of the beam could be exposed to as much as 57 mW/cm^2 for brief periods of time. There are no endangered or threatened flying animals in the area, and the few airborne fauna would spend such little time in traversing the main beam that adverse biological effects should not occur.

For local airborne biota, minor localized effects may occur in the near-field volume specified above. The RFR from SEPP might tend to cause birds to avoid the radar, thereby helping to eliminate the possibility of birds striking it (see Tanner and Romero-Sierra, 1969). On the other hand, birds might learn to seek out the RFR for warmth during cold weather (Gandhi et al., 1978). On the basis of existing information, the anticipated effects, if any, on birds are unclear. Moreover, RFR-induced biological effects may vary among bird species, because the SARs may be species-dependent. However, any potential thermal effects from SEPP would be of very short duration as well as very localized.

Nonthermal effects on birds from low-level RFR have been claimed by a few researchers (Tanner, 1966; Tanner et al., 1967), but the methodology used in these experiments has been questioned (Krupp, 1976; Eastwood, 1967). Temperatures of the experimental subjects were not measured, and the effects may have been thermal. Irrespective of whether the effects were thermal or nonthermal, the experimental arrangements (caged birds in highly restricted areas with horn antennas mounted on the cages) bear little relationship to the habitats in which birds normally operate. Tanner and Romero-Sierra (1974) themselves have concluded

that external environmental parameters such as temperature, humidity, and atmospheric pressure, as well as internal factors of the experimental subject, should be considered when analyzing RFR effects on organisms.

The RFR fields from SEPP will be similar to those of existing military and civilian radar systems that have been operating continuously for many years without any evident ecological damage. In addition, for more than a decade, animal behaviorists and ornithologists have considered radar as a legitimate tool for studying animal migration, navigation, and homing (Eastwood, 1967; Krupp, 1976; Williams et al., 1977; Schmidt-Koenig and Keeton, 1978).

Gary and Westerdahl (1978) summarized reports in the literature on various effects of exposure of insects to RFR. The effects ranged from unrest to death, depending on the level and duration of the exposure and the species studied. In laboratory studies, abnormal development of beetle pupae was reported at power densities and exposure durations that produced significant heating (see Section 4.1.1.2.6.3). In a recent study (Westerdahl and Gary, 1981), adult honey bees were exposed to 2.45-GHz CW RFR at power densities from 3 to 50 mW/cm^2 for durations of 0.5 to 24 hr, after which they were held in an incubator for 21 days to determine the consumption of sucrose syrup and to observe mortality. No significant differences were found between RFR-exposed and sham-exposed or control bees. In another study, Gary and Westerdahl (1981) found that foraging-experienced honeybees retained normal flight, orientation, and memory functions after exposure to 2.45-GHz CW RFR at power densities from 3 to 50 mW/cm^2 for 30 min.

In summary, no significant biological effects from exposure to the main beam of SEPP are expected. At most, only a few airborne individuals of fauna common to the area might be affected in a localized area near the radar, and even these effects may not be hazardous.

4.1.1.4.2 Ground and Near Ground-Level Exposure. Plants and animals at the ground and near-ground levels will be exposed to power densities much lower than those of the main beam. Table 4-5 presents the approximate areas and locations of land near SEPP that are calculated to receive various power densities at ground level. (Exposure at higher elevations can be calculated from Figures 4-2 and 4-3.)

Power density levels incapable of producing substantial heating are not likely to have adverse effects on living organisms (see Section 4.1.1.2). The only ground region that will receive RFR power density levels greater than 1 mW/cm^2 is a small (less than 0.5 acre) area immediately adjacent to the radar. This area will be cleared of all vegetation and have an 8-ft-high security fence that will keep large animals, including deer and cattle, from straying into the area.

With respect to possible RFR-induced cataracts, the cataractogenesis threshold found in laboratory animals is about 150 mW/cm^2 (see Section 4.1.1.2.6.4.2). Thus, it is most unlikely that RFR from SEPP will cause

Table 4-5

AREA AND LOCATION OF LAND TO RECEIVE VARIOUS POWER DENSITIES AT GROUND LEVEL FROM SEPP

Ground Level RFR Power Density (mW/cm^2)	Area of Land To Be Affected (acres)	Habitat Type To Be Affected
1.0 - 4.0	4	Within security fence; cleared land, no vegetation
0.1 - 1.0	45	Extending from security fence to the 1,000-ft exclusion fence; trees and underbrush[a]
0.03 - 0.1	400	Extending from the exclusion fence to 2,000 ft beyond the exclusion fence; trees, underbrush, and swamp[a]

[a]Power densities in these areas are likely to be lower by a factor of ten because of foliage attenuation.

cataracts (or any other ocular abnormalities) in deer and other large mammals (e.g., cattle) if they should enter the area.

The area of trees and underbrush immediately surrounding the security fence has been calculated to receive, at most, 0.3 mW/cm^2 of RFR. In the area from the security fence to the 1,000-ft outer boundary of the exclusion fence, the power density has been calculated to decrease to 0.1 mW/cm^2, which occurs only near the beam overlap azimuth of 130 deg. About 2,000 ft beyond the exclusion fence, the power density has been calculated to decrease to 0.03 mW/cm^2. A total of about 450 acres of natural habitat lies within this area, of which only about one-fourth will be exposed to power densities of RFR that exceed 0.03 mW/cm^2.

In summary, ecological effects from ground- or near-ground-level RFR exposure from SEPP outside the exclusion fence are not anticipated because of the low power density levels in that region.

4.1.2 Biophysical Impacts

4.1.2.1 Plants and Animals

No state or federally listed endangered or threatened plants or animals were found on the 10-acre construction site or on the surrounding 60-acre safety zone at Robins AFB. In addition, no large diseased

trees suitable for red-cockaded woodpecker habitat were located at the proposed PAVE PAWS site. Thus, no critical habitats would be affected by project construction. Although a short section (700 ft) of the fencing and road would be located in the mesic hardwood vegetation type within the 100-yr floodplain of Sandy Run Creek, the area affected would be small, and the impact would not be significant (see Figure 3-1).

Construction of the PAVE PAWS facility would affect approximately 1.5 miles of an existing 2.5-mile nature trail in the northeastern portion of the proposed site. The trail begins at the Nature Center and continues through pine and mixed pine-hardwood. Although the proposed PAVE PAWS site is not a unique habitat in the region, it does contain forested trails used for educational purposes.

As a mitigating measure, other undeveloped areas on the base may be set aside for nature trails to replace those lost by the construction of SEPP. Since no areas in the immediate vicinity of the Nature Center are available for trail construction, the Unique Natural Area along Horse Creek is a potential site for trails.

Activities associated with operation of SEPP would have no significant negative effect on any fauna and flora on Robins AFB.

4.1.2.2 Air and Noise

4.1.2.2.1 Air. During construction of SEPP, air pollutants will be emitted as a result of vehicle traffic and equipment operation. Approximately 100 construction workers will be commuting to the site during peak construction activity, and large equipment will be employed for site preparation and facility construction. In comparison to current daily automobile emissions generated by the cars of the approximately 20,500 persons who work on Robins AFB, incremental automobile engine emissions during construction are likely to be insignificant.

Table 4-6 indicates estimated emissions attributable to heavy-duty construction equipment comparable to that which will be employed at the SEPP site. With the exception of nitrogen oxides, hourly emissions from one piece of construction equipment are comparable to or less than those associated with one landing and takeoff cycle of the military aircraft based at Robins AFB. Table 4-7 provides emission factors per military aircraft engine; transport planes have four engines and jets have one or two.

If two pieces of each type of equipment identified in Table 4-6 were to be operated continuously during each work day of the first year of the 24-month construction period, total emissions generated would be 11 tons of carbon monoxide, 3 tons of hydrocarbons, 32 tons of nitrogen oxides, 2 tons of sulfur oxides, and 2 tons of particulates. These incremental pollutant emissions would constitute less than 5% of total pollutant emissions generated annually on Robins AFB, except for nitrogen oxide emissions, which would constitute 7%.

Table 4-6

EMISSION FACTORS FOR HEAVY-DUTY DIESEL-POWERED CONSTRUCTION EQUIPMENT

Type of Equipment	Emission Factor (lb/hr)				
	CO	HC	NO_x as NO_2	SO_x as SO_2	Particulates
Wheeled tractor	2.150	0.148	0.994	0.090	0.136
Wheeled dozer	0.739	0.234	5.050	0.348	0.165
Scraper	1.460	0.626	6.220	0.463	0.406
Motor grader	0.215	0 054	1.050	0.086	0.061
Wheeled loader	0.553	0.187	2.400	0.182	0.172

Source: Golden et al. (1979).

Table 4-7

EMISSION FACTORS PER AIRCRAFT LANDING AND TAKEOFF CYCLE

Type of Aircraft	Emission Factor (lb/engine)				
	CO	HC	NO_x as NO_2	SO_x	Particulates
Military transport	5.7	2.7	2.2	0.41	1.1
Military jet	15.1	9.93	3.29	0.76	0.31

Source: Golden et al. (1979).

In addition to engine emissions, dust would be created by all types of vehicle traffic; however, the construction contractor plans to pave the access road to the site early in the construction period. In unpaved areas, salt would be spread to reduce fugitive dust (particulates) generated by construction equipment (Van Keuren, 1982).

During SEPP operation, the automobiles of about 260 people commuting to the site each day and the intermittent use of diesel generators will create air pollutants. Three generators located in the power plant directly behind the radar (see Figure 4-6) will provide back-up electricity in case a severe storm or system overload causes a brownout or blackout in the commercial power grid. To predict how often the generators will actually be needed to provide electricity to SEPP is difficult, but they will likely be operated no more than 15 hr/month (5 hr per month each) for testing and maintenance purposes. Air Force regulations require a minimum of 2 hr/month of engine usage.

For this analysis, it is assumed that the power plant will contain three 3,300-kW diesel generator sets. The emissions for each generator will be directed through a 60-ft (from ground level) exhaust stack into a silencer. The three stacks will be located alongside the power plant 30 ft apart. EPA recently revised air pollutant emission factors for large stationary diesel generators. Emission factors for these generators, assuming no emission controls, are 3.9 g/kWh for CO, 0.08 g/kWh for hydrocarbons, 15.0 g/kWh for NO_x, and 4.3 g/kWh for SO_x (U.S. Environmental Protection Agency, 1982). Particulate emissions are considered to be negligible (Sutherland, 1982). If these factors are used for estimation purposes, hourly emissions from the power plant, assuming only one generator is operating at one time, would be roughly 28 lb of CO, 0.6 lb of hydrocarbons, 109 lb of NO_x, and 31 lb of SO_x. Annual emissions would be 2.6 tons of CO, 0.05 ton of hydrocarbons, 9.8 tons of NO_x, and 2.8 tons of SO_x. Without controls, the SEPP power plant at Robins AFB on an annual basis would increase CO emissions by 0.1%, NO_x emissions by 2.4%, and SO_x emissions by 4.8%. Nitrogen oxide and sulfur oxide control techniques would reduce these incremental emissions noticeably.

A small domestic hot water boiler will be in the gatehouse and two hot water boilers, as well as a steam generator, in the power plant. The pollutant emissions from these units will not be significant.

In summary, carbon monoxide, hydrocarbon, and particulate emissions associated with construction and operation of SEPP are not expected to be significant relative to total emissions on Robins AFB. Aircraft activities alone annually contribute 1,065 tons of carbon monoxide, 656 tons of hydrocarbons, 135 tons of nitrogen oxides, 26 tons of sulfur oxides, and 16 tons of particulates to the local atmosphere. In 1981, total air pollution emissions on Robins AFB were 2,250 tons of carbon monoxide, 1,122 tons of hydrocarbons, 406 tons of nitrogen oxides, 58 tons of sulfur oxides, and 51 tons of particulates (Bioenvironmental Engineering Services Division, 1982). Because Robins AFB is in an AQCR that is in attainment of federal air quality standards and because air quality

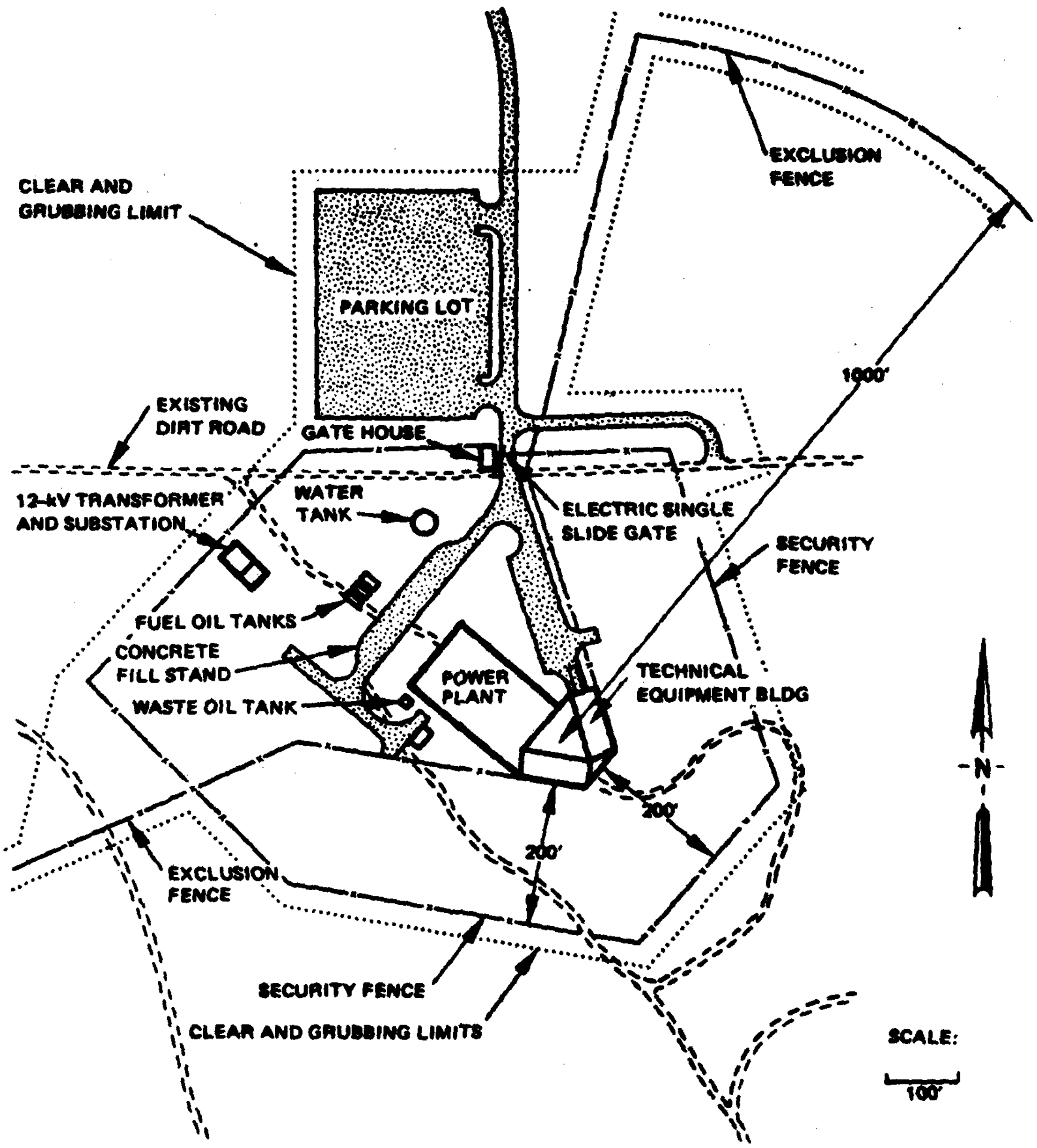


FIGURE 4-6 PROPOSED SITE PLAN FOR PAVE PAWS

levels at the nearest monitoring stations are in compliance with federal and state requirements, it is not likely that the incremental emissions from SEPP will cause regional air quality to exceed permissible levels.

4.1.2.2.2. Noise. Noise from site grading, clearing, and preparation (including road paving and fence construction) will last about 6 to 8 months and from excavation, foundation, and erection work about 18 months. Scrapers and dozers will be used during the former period and graders and shovels during the latter. Concrete trucks and large (40-ft) flatbed trailers will also be transporting equipment to the site during the excavation, foundation, and erection work. Table 4-8 presents estimations of noise levels resulting from various construction activities. All during construction, a relatively small amount of additional vehicle traffic noise will be generated by workers temporarily commuting to the site.

The sound of construction activities will be noticeable at the nature trails in the recreational area adjacent to the site. The noise is also likely to be audible at the shooting range and water tower (both

Table 4-8

NOISE LEVELS ASSOCIATED WITH CONSTRUCTION EQUIPMENT

Source	Peak Noise Level (dBA)	Distance from Source (ft)			
		50	100	200	400
Heavy trucks	95	84-89	78-83	72-77	66-71
Dump trucks	108	88	82	76	70
Concrete mixer	105	85	79	73	67
Jackhammer	108	88	82	76	70
Scraper	93	80-89	74-82	68-77	60-71
Dozer	107	87-102	81-96	75-90	69-84
Paver	109	80-89	74-83	68-77	60-71
Shovel	111	91	85	79	73
Crane	104	75-88	69-82	63-76	55-70
Loader	104	73-86	67-80	61-74	55-68
Grader	108	88-91	82-85	76-79	70-73
Caterpillar	103	88	82	76	70
Dragline	105	85	79	73	67
Shovel	110	91-107	85-101	79-95	73-89
Pile driver	105	95	89	83	77
Ditcher	104	99	93	87	81
Fork lift	100	95	89	83	77

Source: Golden et al. (1979).

about 1,600 ft away), but it will probably not be distinguishable from background levels at the nearest base housing area (approximately 4,800 ft to the northwest), the Nature Center (4,000 ft to the north), or the storage area (3,500 ft to the west) (Figure 4-7).

Table 4-9 indicates the effect on humans of certain noise levels.

The construction contractor indicates that the use of bolted steel frame sections in construction of the main SEPP building will result in lower noise levels than might occur using other construction methods (Van Keuren, 1982).

Predicting the effects of construction noise on wildlife is difficult, but it has been determined that animals adapt to regular predictable noise or continuous noise more readily than to sporadic noise bursts. Wilderness species appear more sensitive to noise exposure than domestic animals, and animals in a herd react more strongly than do single animals. Because local species at Robins AFB are accustomed to aircraft takeoffs and landings, weapons testing, and other sources of loud noise, it is unlikely that they will be adversely affected by construction noise at the SEPP site.

Table 4-9

IMPACT OF NOISE ON HUMANS

Noise Level (dBA)	Effect
140	Potential hearing loss
135	Very painful
125	Pain threshold
115	Maximum vocal effort
95	Severe hearing damage
90	Affect mental and motor behavior
85	Very annoying
80	Moderate hearing damage
75	Changed motor coordination
70	Smooth muscles/glands react
65	Annoyance, communication interference
50	Moderate sleep interference
35	Slight sleep interference
25	Hearing threshold
20	No sound perceived

Source: Golden et al. (1979).

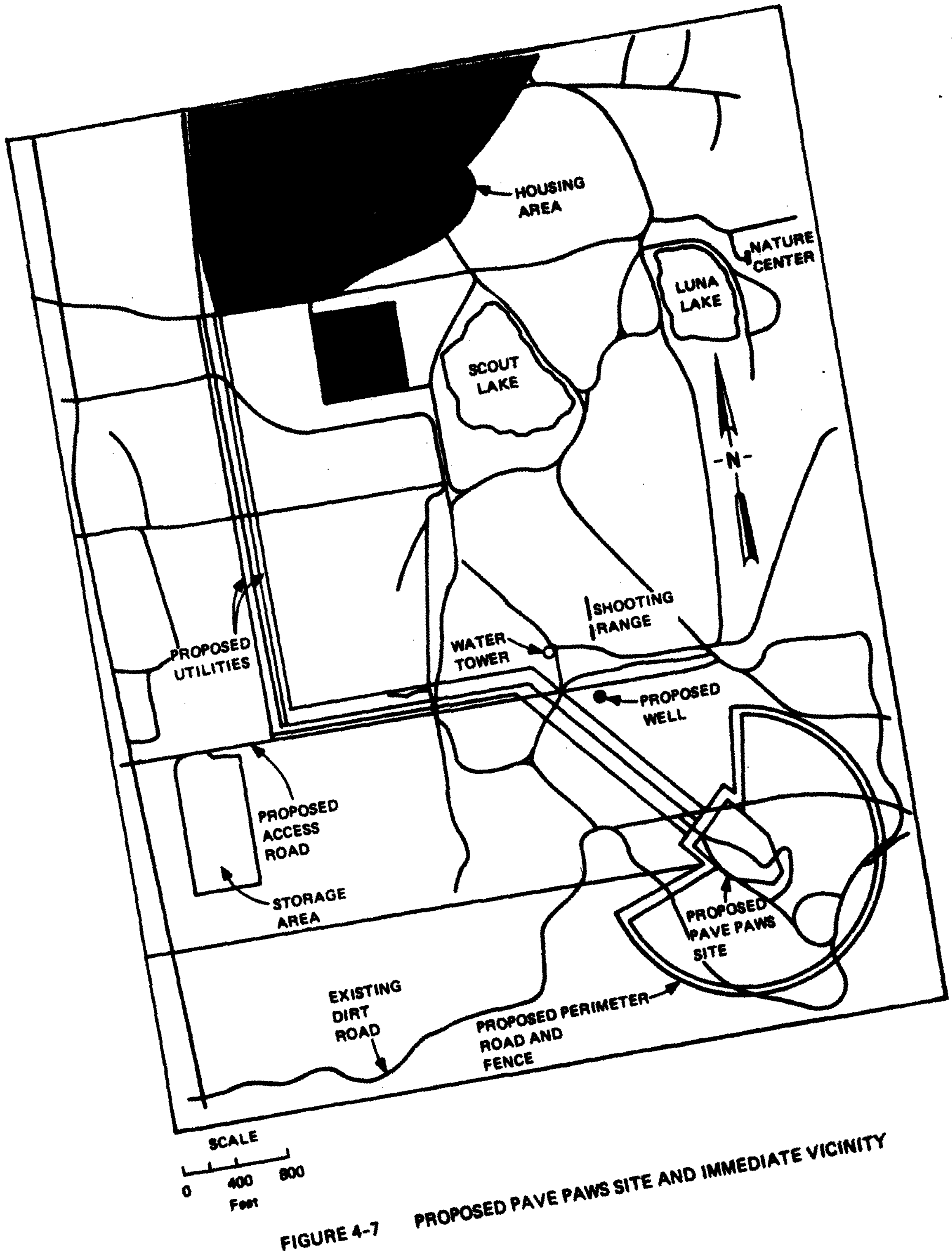


FIGURE 4-7 PROPOSED PAVE PAWS SITE AND IMMEDIATE VICINITY

During SEPP operation, noise will be generated by the automobiles of operations personnel, by the diesel generators in the power plant, and by the cooling equipment. The diesel generators will operate on an irregular schedule as required for power and maintenance. The inside of the power plant and the chiller room and air conditioner fan area inside the radar building would be designated as noise hazard areas. For example, noise levels would be about 110 dB at the engines, 85-90 dB near the chillers, and 80 dB elsewhere in the power plant. An exhaust silencer will be placed on the outside of the power plant for each generator; noise levels in the exhaust stack area would be roughly 90 dB. At the outside back wall of the SEPP building, noise levels are expected to be 85 dB (Hassett, 1982).

The cooling equipment operates continously; from 20 ft its noise level is estimated to be approximately 60 dB. At a distance of about 50 ft, the noise level from the cooling towers would be about 52 dB. Sounds from the power plant and cooling towers are not expected to be loud enough to interfere with normal conversation at the building entrance (60 dB), inside the radar building (40 dB), or at the gate house. Noise from operation of SEPP is not likely to be noticeable beyond the site itself.

4.1.2.3 Water

4.1.2.3.1 Hydrology. In the Warner Robins region, domestic and industrial water supplies are obtained from the Tuscaloosa Formation, a sand aquifer. While demand for water has increased during the last several decades as Warner Robins and Robins AFB have grown, there has not been a significant drawdown or a cone of depression in the water table.

A new well would be drilled on Robins AFB to satisfy the water requirements of SEPP. The project plan includes locating a well approximately 1,600 ft northwest of the construction site (see Figure 4-7). The capacity of the well will be determined when it is drilled. From the well, water will be piped to and temporarily stored prior to use at the site in an aboveground 250,000-gal tank that will be placed inside the 200-ft security fence (see Figure 4-6).

The well would provide water for equipment cooling, make-up, domestic uses, and fire protection. SEPP will require 1,800 gal of water for cooling the radar equipment and 3,600 gal (600 gal per engine) for cooling the diesel generators. All this water will be continuously recirculated. On a daily basis, operations personnel will require approximately 7,500 gal for potable and sanitary use (assuming 30 gal per person per shift). The construction contractor will determine the water demand of the sprinkler system in the power plant and radar building. Well water will be treated before it is used either at the storage tank or inside the radar building. Withdrawal and use of this quantity of groundwater is likely to have minimal effect on the Tuscaloosa sand aquifer, in view of its historical performance.

4.1.2.3.2 Water Quality. On Robins AFB, SEPP would be constructed on a sedimentary formation consisting of sand, clay, and gravel. Average depth to the bedrock underlying the local area is 4,000 ft.

Soil test borings of an area adjacent to the SEPP site indicate that the underlying aquifer is approximately 11 to 21 ft below ground level. At this depth, the aquifer could be disturbed by construction activity. In addition, if any contaminants were to mix with groundwater encountered during foundation work, they could adversely affect water quality at the new well that would be drilled 1,600 ft from the site. The construction contractor plans to take all necessary precautions to minimize the effects of construction on the integrity of the local aquifer and on groundwater quality (Hassett, 1982).

Excess surface runoff at the site would be channeled into natural drainage ways in the area that feed Sandy Run Creek. During construction, this runoff could contain road salt (used to prevent dust during construction) and oil and gasoline (from construction equipment).

One potential source of water contamination during project operation is the leakage or spills from diesel fuel handling and storage facilities associated with the power plant generators. Several steel tanks with a total capacity of 150,000 gallons would be installed under the 10-acre construction site for diesel fuel storage. Fiberglass tanks may be used to preclude corrosion. The location of the fuel storage facilities and a plan for preventing fuel spills, or mitigating their impact should they occur, will be specified by the construction contractor. A 2,000-gal waste lube oil tank would be located next to the power plant (United Engineers and Constructors, undated). The tank contents would be pumped to an oil truck for removal from the site.

The wastewater generated by SEPP would be primarily domestic waste because water from the equipment cooling and chilled water systems would be circulated to the cooling towers for evaporation. This wastewater would be transported by buried pipe from the project site to the water tower that is approximately 2,000 ft northwest of the radar. At the water tower, wastewater from SEPP would join the base wastewater collection network and be routed to the main sewage disposal plant for treatment. Average flow into the sewage treatment plant on Robins AFB is well below capacity; however, during periods of heavy rainfall, demand on the facility is in excess of capacity. In normal periods, the plant will be able to treat the wastewater from SEPP. Base engineers are currently trying to mitigate periodic problems at the plant (Milligan, 1982).

4.1.2.4 Land and Minerals

4.1.2.4.1 Geology. Construction of SEPP in the southeastern corner of Robins AFB would not affect the local geological pattern. None of the proposed structures (except the water well) entail deep drilling activities, so the geology would remain unaltered.

4.1.2.4.2 Soils. The surface terrain at the SEPP site slopes gently southward towards Sandy Run Creek with a gradient ranging from 0% to 2.5%. Site preparation activities and access road and utility corridor construction would leave flattened, exposed surfaces and low banks devoid of vegetation, which would be susceptible to runoff and some erosion. Reseeding to replace the original ground cover with binding grassland vegetation or spreading gravel around the construction site could prevent erosion.

Foundation requirements of the SEPP facilities are well within the established bearing strength of the soil cover of most of Robins AFB. Therefore, no adverse effects on the terrain are anticipated from the installation of the PAVE PAWS facility.

4.1.2.4.3 Minerals. Kaolin is Georgia's principal mining product, and important open-pit kaolin mines are in the adjacent counties to the north and east of Robins AFB. Driller's logs of the waterwells on the base note "stringy layers" of kaolin, but never in sufficient thickness to suggest that further exploration is advisable or that mineable quantities are to be found. The PAVE PAWS project would not prevent future mineral-based industry on Robins AFB.

4.1.2.5 Natural Disasters

4.1.2.5.1 Earthquakes. According to the U.S. Geological Survey's seismicity map and earthquake records for Georgia, two of the 36 earthquakes that have occurred in the state since 1826 were located in the Robins AFB vicinity. One was of moderate and the other of fairly strong intensity; both were one-time occurrences. This historical experience indicates that a major earthquake (VIII to XII on the modified Mercalli scale) is not likely to affect SEPP at Robins AFB.

On the seismic zone map used by the Air Force for project design purposes, Robins AFB is on the border between Zone 1 (minor damage) and Zone 2 (moderate damage) (U.S. Air Force, Manual 88-3). The PAVE PAWS installation will be designed to reflect the seismic probability associated with these zones (Hassett, 1982). If an earthquake of greater intensity did occur at Robins AFB and SEPP was damaged while operating, no adverse impact to the biophysical environment or to the local population would result, but operating personnel could be injured.

4.1.2.5.2 Fires. A forest fire on property adjacent to the 100-acre PAVE PAWS site would probably be stopped by the 60-ft-wide perimeter fence corridor that would act as a fire break. Although lightning could cause a fire in the forested safety zone between the 200-ft security fence and the 1,000-ft hazard fence, the 10-acre PAVE PAWS site would be kept clear of vegetation, thereby preventing a fire from spreading to the immediate vicinity of the radar.

Water in the 250,000-gal storage tank would be used to fight a fire threatening the facilities inside the security fence. From the storage tank, water would be distributed to outside fire hydrants, fire pumps in

the power plant, and booster pumps in the radar building. A CO_2 system in the power plant and a halon hose system in the radar building would be available for fighting fire (Raytheon PAVE PAWS Program Office, 1979). Should the radar catch fire, the subsequent effect on the biophysical environment would not be worse than that of the fire itself.

4.1.2.5.3 Floods. The SEPP radar building would be constructed at a location 275 ft in elevation and slightly above the 100-yr floodplain of Sandy Run Creek. A segment of both the 1,000-ft perimeter fence and road, however, would cross the floodplain and could be damaged in the event of a major flood. Nevertheless, damage to the fence and road would not additionally affect the biophysical environment.

4.1.2.5.4 Storms. Although a severe storm such as a tornado could damage SEPP, its destruction would not cause additional incremental damage to the biophysical environment beyond the damage caused by the storm.

4.1.3 Socioeconomic Consequences

For this analysis, the socioeconomic consequences of constructing and operating of SEPP were estimated with the aid of the local economic consequences (LECS) model (Hamilton and Webster, 1980; Pierce, 1978) and the methodologies set forth in the Socioeconomic Impact Assessment Methodology Handbook (Pierce et al., 1978), each developed by SRI International for the Air Force in 1978.

4.1.3.1 Employment

Employment in the Robins AFB would increase through the direct jobs created to construct and operate the SEPP, as well as through those generated indirectly by personal spending and procurement during construction and operation.

Figure 4-8 depicts the overall schedule and manpower requirements of SEPP. Design and construction is expected to take about 36 months. After all design work is completed, the site will be prepared (e.g., installation of fencing, guardhouse, utilities, and paved roads), the SEPP building and power plant will be constructed, and the electronics will be installed and tested. The operational work force will be assigned during construction, and many personnel will undergo training until the system is operational.

Site preparation, which would cost about $5 million,* would likely be completed by a local contractor. The peak work force is expected to be about 25. The SEPP building and power plant would cost about $20 million and be constructed under the management of Raytheon Co., which expects to have a five-person construction management group

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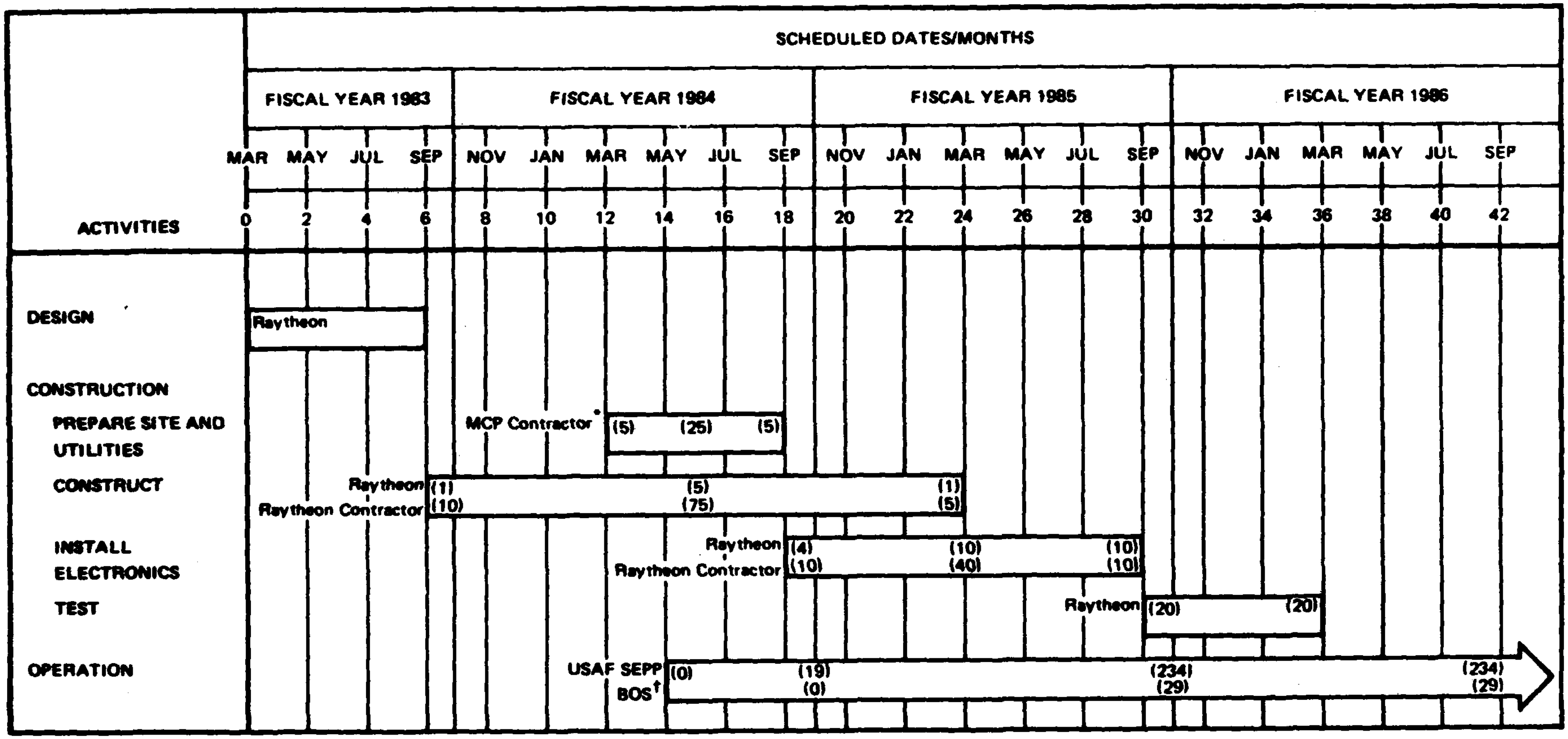
*All figures are in 1980 dollars unless noted otherwise.



*Military Construction Program (MCP)

†Base Operation and Support (BOS) Personnel

NOTE: Numbers in parentheses represent the size of the work force.

SOURCES: Van Keuren (1982); Hassett (1982); Paul; SRI International

FIGURE 4-8 SEPP SCHEDULE AND MANPOWER REQUIREMENTS

on site. Raytheon would subcontract the actual construction and the builder would probably have a maximum work force of 75. Raytheon would have about 10 people on site to install the electronics and would hire another 40 from its subcontractor to assist. Testing would be carried out by 20 Raytheon employees.

Construction activities are expected to tap the local construction work force. If contractors from outside the region were successful bidders, they would likely bring in their own management but hire local workers. All Raytheon employees would be from outside the region. The operational work force is expected to consist of 220 military and 14 civilians. It is assumed that the civilians would be hired from the local work force. An estimated 29 additional military personnel would be transferred to Robins AFB to meet the added base support requirements generated by SEPP.

A composite of the personnel required is presented in Figure 4-9. The construction work force would peak at about 100 in the fifteenth month. The operational and support work force would level out at about 260 at the end of the second year.

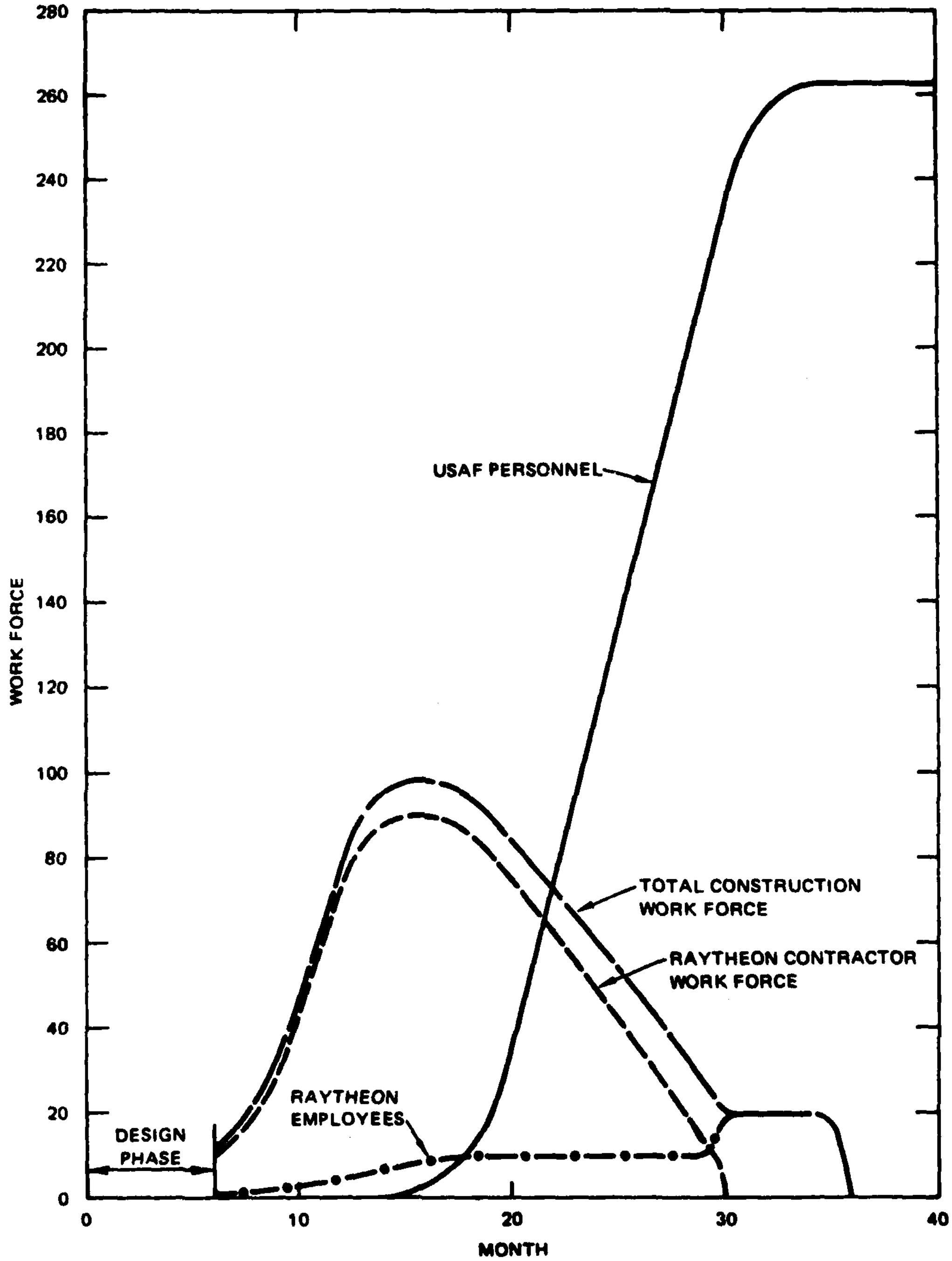
Primary consideration is being given to relocating the Alternate Space Defense Operations Center Computation Center (ASCC) to the SEPP site when the FPS-85 radar system at Eglin AFB is deactivated in 1988. This could result in the addition of 20 personnel around month 64.

Construction workers would spend an estimated $3.0 million in the ROI during the 2.5-yr construction period. The construction companies would spend another $3.2 million on goods and services. This spending could generate 40 new jobs in the service and trade sectors. However, because the peak construction activity would last less than 1 yr and the national economy, particularly the construction sector, is depressed, local business people are expected to resist hiring new staff and seek greater productivity from their current employees (Chalmers, 1977).

The operational work force is expected to spend $2.4 million per year in the ROI. This plus $3.1 million in annual procurement would generate demand for about 80 new positions in the service and trade sectors of the ROI's economy. Given the permanence of the SEPP work force, many of the 80 jobs are likely to be filled. The operation of PAVE PAWS would reduce unemployment in the ROI in 1985 by 0.07%.

4.1.3.2 Population

It is assumed that most of the construction work force will be hired locally. Those from outside the region would either commute from their present residence or temporarily relocate (without family) in the ROI. Because the influx of Air Force personnel during operation would far exceed the number of construction workers who might relocate, and because the Air Force workers would be accompanied by their dependents and would stay in the region for an extended period of time, they would be the primary source of population change.



SOURCE: Van Keuren (1982); Hassett (1982); SRI International

FIGURE 4-9 CONSTRUCTION AND OPERATION WORK FORCE

In 1985, the Air Force operational work force would consist of 263 persons--220 SEPP military, 14 SEPP civilians, and 29 base operation and support (BOS). Assuming that the civilians are hired locally and applying the average family size for the military assigned to Robins AFB, the total population increase would be about 580, or 0.2% of the projected 1985 population of the ROI. This would increase the projected average annual growth from 1.1% per year to 1.2% during 1984 and 1985. Of the 580, 500 are expected to reside in Houston County. This is 0.6% of the projected 1985 population of the county and would increase the projected growth rate from 1.7% to 2.0%.

The influx of Air Force personnel is not expected to cause secondary population growth in the ROI. In June 1982, about 6,500 people in the ROI were unemployed. The less than 100 secondary jobs would likely be absorbed by the local labor force.

Both the anticipated rate and absolute amount of population growth are small and unlikely to cause significant adverse effects. Subsequent analyses address the ability of particular elements of the infrastructure (e.g., housing, educational facilities) to accommodate the expected increase.

4.1.3.3 Income

Changes in total personal income in the ROI would result directly from salaries of contractor and Air Force personnel and indirectly from spending for personal items, procurement, and construction. During the construction period about $3.2 million in personal income would be created. Operation of SEPP would generate $6.3 million in personal income annually, about 0.3% more than expected in 1985 if SEPP were not built.

4.1.3.4 Housing

In 1984 and 1985, 249 Air Force households are expected to seek housing in the ROI. The 220 SEPP military personnel include: 16 officers, 7 E-8s and 9s, 190 E-4s to E-7s, and 7 E-1s to E-3s. On the basis of projected manpower levels at Robins AFB (see Table 3-6), base housing will be at capacity in 1984 and 1985 as it is currently (FY 82). Although many families may register on the waiting list for military housing and may ultimately be placed, it is assumed, as the worst case, that all families will seek off-base housing.

On the basis of the present distribution of Robins AFB military personnel, 94% of the SEPP and BOS work force (or 234 people) would seek housing in Houston County. About 60 would likely seek homes to own and 170 would want rentals (USAF, 1982d). This represents 0.3% of the portion of the projected 1985 housing stock that is owned and 1.2% of the portion that is rented.

The significance of potential impacts caused by this demand cannot be assessed accurately because of turbulence in the housing industry.

Even if the poor market conditions of July 1982 prevail in 1984 and 1985, however, incoming personnel are likely to find housing.

Units for sale across the price range are plentiful, and those with the means to buy should be successful. Rentals are not as readily available. The present vacancy rate is estimated to be less than 5%, and the Air Force demand could push it below 4%. This would create an extremely tight rental market.

If such conditions do exist, Air Force personnel are likely to spend more than they desire for rent, rent substandard units, or rent units farther from the base than desired. The housing stock in Bibb County is largely untapped by the military from Robins AFB. In 1980 more than twice as many rentals were vacant in Bibb County than in Houston County; Bibb County could thus serve as an additional resource if required.

The housing in the ROI is among the most affordable in the United States; nonetheless, the lower ranking enlisted personnel may have to pay more than they desire for housing. The greatest problem may be encountered by any of the 7 E-1 to E-3s who have families.

In summary, if the housing market in 1984-1985 is healthy, as in the years before 1980, it will adequately accommodate SEPP personnel. If the more difficult conditions of July 1982 prevail, Air Force families will find housing, but may be forced to contend with higher prices, lower quality, and longer distances to commute.

Part of the construction work force would reside in motels and hotels in the ROI. This will include up to 20 Raytheon employees and perhaps a dozen or more other workers. They can easily be accommodated in the 1,500 hotel and motel rooms in Warner Robins and Perry. On average, more than 500 rooms are vacant at any given time.

4.1.3.5 Education System

Over a 2-year period commencing in FY 1984, approximately 220 SEPP and 30 BOS military personnel would enter the region. Assuming that the residential distribution of these personnel duplicates that of the personnel currently assigned to the base, 234 of the SEPP personnel would live in Houston County. On the basis of the current ratio of 0.44 student per Air Force personnel, about 100 school age children would accompany the SEPP personnel who would reside in Houston County.

Houston County School District officials do not anticipate that the school system will have any problem accommodating these 100 additional students. Declining enrollment over the past few years has created excess capacity in most district schools, and further enrollment reductions are expected. If a large percentage of these new students reside within the service boundaries of one or both schools without excess capacity, the district boundaries could be easily adjusted to redistribute the student load to eliminate any overcrowding. This will probably not be necessary, however, given the small number of students involved.

4.1.3.6 Community Facilities and Services

Warner Robins is the largest city in the county, housing more than half of the county population, and the closest city to the base. Warner Robins has grown substantially over the last 20 years, with population increases of 79.7% in the 1960s and 19.1% in the 1970s. Representatives of the various city departments believe that the city has adequately responded to the growing needs for public services and facilities and will be able to meet any future service needs generated by the base. The city sewage plant is the only facility currently lacking excess capacity. The base sewage plant would handle all sewage generated by SEPP personnel residing on base, however, and the City Utility Department officials feel that the city plant will be able to accommodate the load generated by SEPP personnel residing off base in Warner Robins.

Approximately one third of the county population resides in unincorporated areas. Because these areas have been experiencing a boom in housing development since the mid-1960s, the county is accustomed to providing services to a constantly growing population. County officials believe that the current system is adequate to accommodate SEPP personnel and their dependents. A $2 million expansion of the county water system is under way. The county road system is in very good condition and provides good access throughout the county. County fire stations are located throughout unincorporated areas. The remaining county services are similarly adequate.

Georgia Power Company would provide power to operate SEPP. Because Robins AFB is the heaviest user of power in the area, power lines have been designed to handle loads typically required by the base. A coal-fired power plant was recently constructed within 40 miles of the base, and three additional 1,800-MW units are planned. A new nuclear power plant also serves the area. Representatives of Georgia Power Company (1982) feel that more than adequate generating capacity will exist to serve SEPP without adversely affecting the provision of power to other users.

4.1.3.7 Land Use

Some people living close to SEPP may be concerned about potential adverse biological effects. Fewer than 100 residences are located within the first 2 miles of the scan sector. Because of the agricultural zoning, present uses (i.e., agricultural and timber harvesting), large land holdings, and the predominant direction of urbanization, additional urban development in this 2-mile band is unlikely in the foreseeable future. The area west of Highway 247 and north of Highway 96 and Bonaire, which is between 2 and 5 miles away from the proposed site, could accommodate more than 300 single family homes (see Figure 3-3).

In the scan sector within 5 miles of SEPP, no land is zoned for industrial uses and only a small amount is designated as commercial land. A large block of industrial land is located just north of the scan sector on the west side of Highway 247. Consequently, land use that might

affect or be affected by SEPP is unlikely to be developed. If such an event becomes probable, however, mitigation is possible. EMR-sensitive devices can usually be shielded. Often this is not feasible for EMR sources; therefore, such sources would have to be precluded from the vicinity of SEPP. Sources could be controlled with an overlay zone that would prohibit EMR sources of a particular type and power in prescribed areas. This would require the type of coordination between the Air Force and Warner Robins and Houston County that takes place as part of the Air Installation Compatible Use Zone (AICUZ) program.

Electromagnetic interference is of less concern in areas behind the scan sector. However, future EMR sources and EMR-sensitive activities, particularly those on-base, could be affected by the operation of SEPP.

Visitors to the Nature Center located on-base near Luna Lake (approximately 1 mile north of the SEPP site) use 2.5 miles of nature trails, 1.5 miles of which would be made inaccessible by the 1,000-ft exclusion fence. Although other areas suitable for the development of nature trails are available, they are less proximate to the nature center than the present trails.

4.1.3.8 Aesthetics

Most of the SEPP radar system would be contained in a building 105 ft high and approximately 100 ft by 150 ft at its base. The structure would be painted to match the predominant color of the surroundings. At certain times of the day, the sun is likely to reflect from the brushed aluminum surface behind the antenna elements.

The structure would be located at the southern edge of Robins AFB, at the northern edge of a densely forested agricultural area. The SEPP building would protrude about 30 to 60 ft above the surrounding forest. It would be visible from areas where the foreground does not obscure the view.

The building should not be visible from Highway 247 south of the base and Highway 96 because these roads are lined with dense foliage. The top of the structure would be visible from parts of Highway 247 west of the base, the on-base housing area, and tall structures on base and in Warner Robins.

Because of the area's urban development and the expansive industrial context of Robins AFB, the SEPP structure is not likely to be considered a visual intrusion of significance.

4.1.3.9 Cultural Resources

The artifacts occurrences within the 10-acre construction site would be affected by construction, but they are not significant; therefore, no adverse impact is anticipated.

As initially proposed, the SEPP exclusion fence and road would have intersected the prehistoric archeological site, 9Ht8 (see Figure 3-4). Archeological deposits on site 9Ht8 would probably have been disturbed by such construction activities as clearing, grubbing, grading, filling, and soil borrowing along the 60-ft-wide fence and road corridor. Although testing and evaluation of the archeological site have not been conducted to determine whether it is significant and thus eligible for inclusion on the National Register of Historic Places, the Air Force chose to modify the SEPP site plan. The 1,000-ft fence would be constructed so that it includes all of site 9Ht8 in the exclusion zone (see Figure 4-10). At the southeastern edge of the archeologic site, the 1,000-ft fence would jut out about another 450 ft to incorporate the southern half of that site. The fence would be placed 10 ft from the edge of the archeologic site, and no clearing or grubbing would take place near or over the site. The perimeter road would parallel the 1,000-ft fence except that the existing base road, already extending the length of site 9Ht8, would be used rather than constructing a new segment of road between the fence and the site (Figure 4-10). Being inside the perimeter fence would both preserve site 9Ht8 and remove it temporarily from further research consideration or excavation. Archeologists would not be allowed inside the exclusion zone during the lifetime of the SEPP project.

4.2 Moody AFB (Alternate Site)

4.2.1 Radiofrequency Radiation (RFR)

As at Robins AFB, the principal environmental consequences would stem from the RFR produced by operating the radar in the vicinity of Moody AFB.

4.2.1.1 RFR Fields

The radar building and associated equipment would be the same at Moody AFB as that described in connection with Robins AFB, and the resulting RFR would be the same. The only differences would stem from differences in the terrain and in the amount of foliage present.

Figure 4-11 identifies sites and sectors for the alternate location of SEPP, near Moody AFB. Table 4-10 identifies the sites for which RFR calculations have been made and presents the results of those calculations. The configuration of the security and exclusion fences and the values of RFR in their vicinity are expected to be the same as those calculated for Robins AFB; thus, Table 4-1 is also applicable to the Moody site.

4.2.1.2 Human Health Effects

Airborne persons in the surveillance volume of the Moody AFB site would be exposed to the same values of pulse and average power density as those at corresponding distances from the Robins AFB site. Thus, the

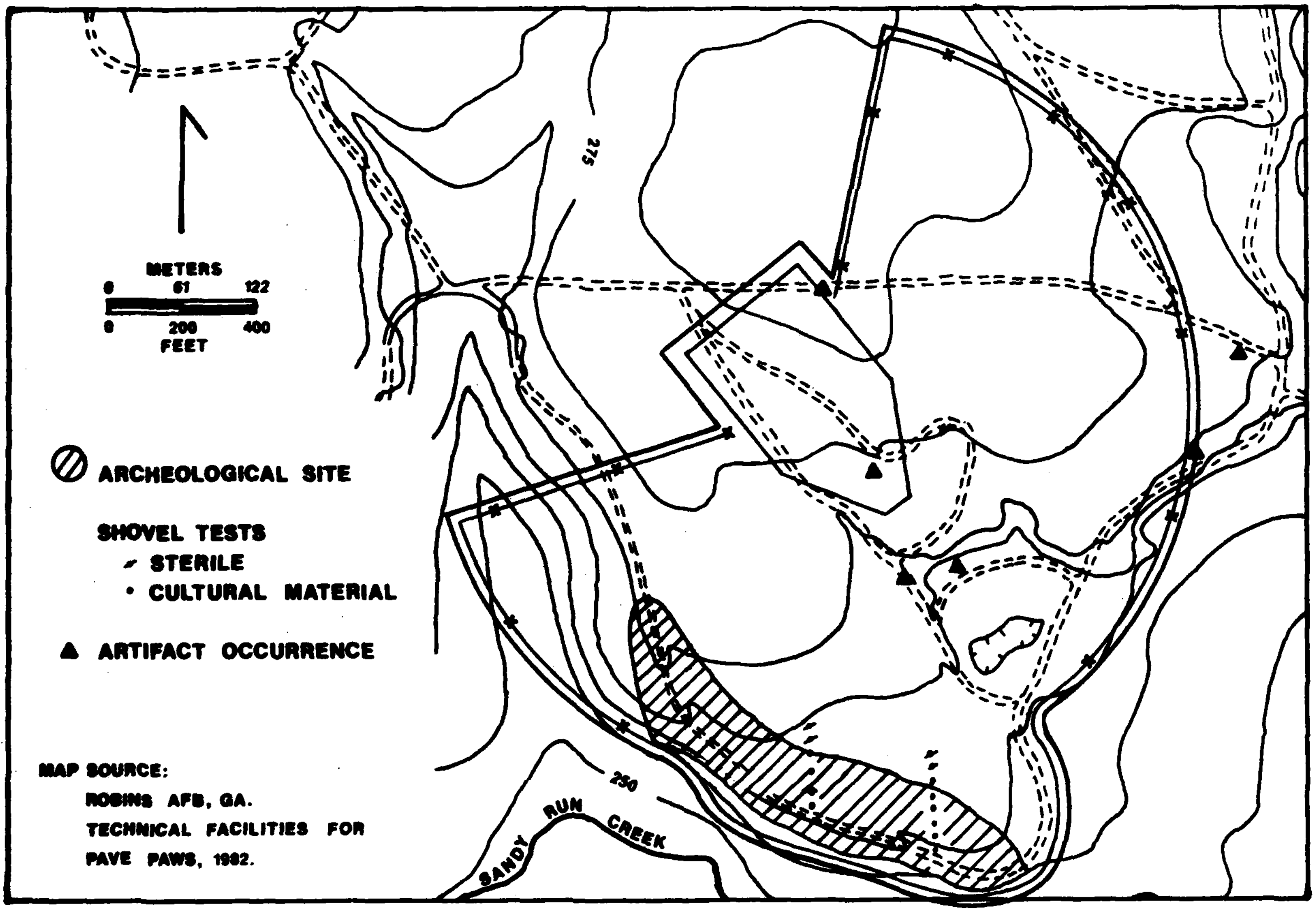


FIGURE 4-10 PROJECT MODIFICATION TO INCLUDE SITE 9Ht8 IN THE PAVE PAWS SAFETY ZONE

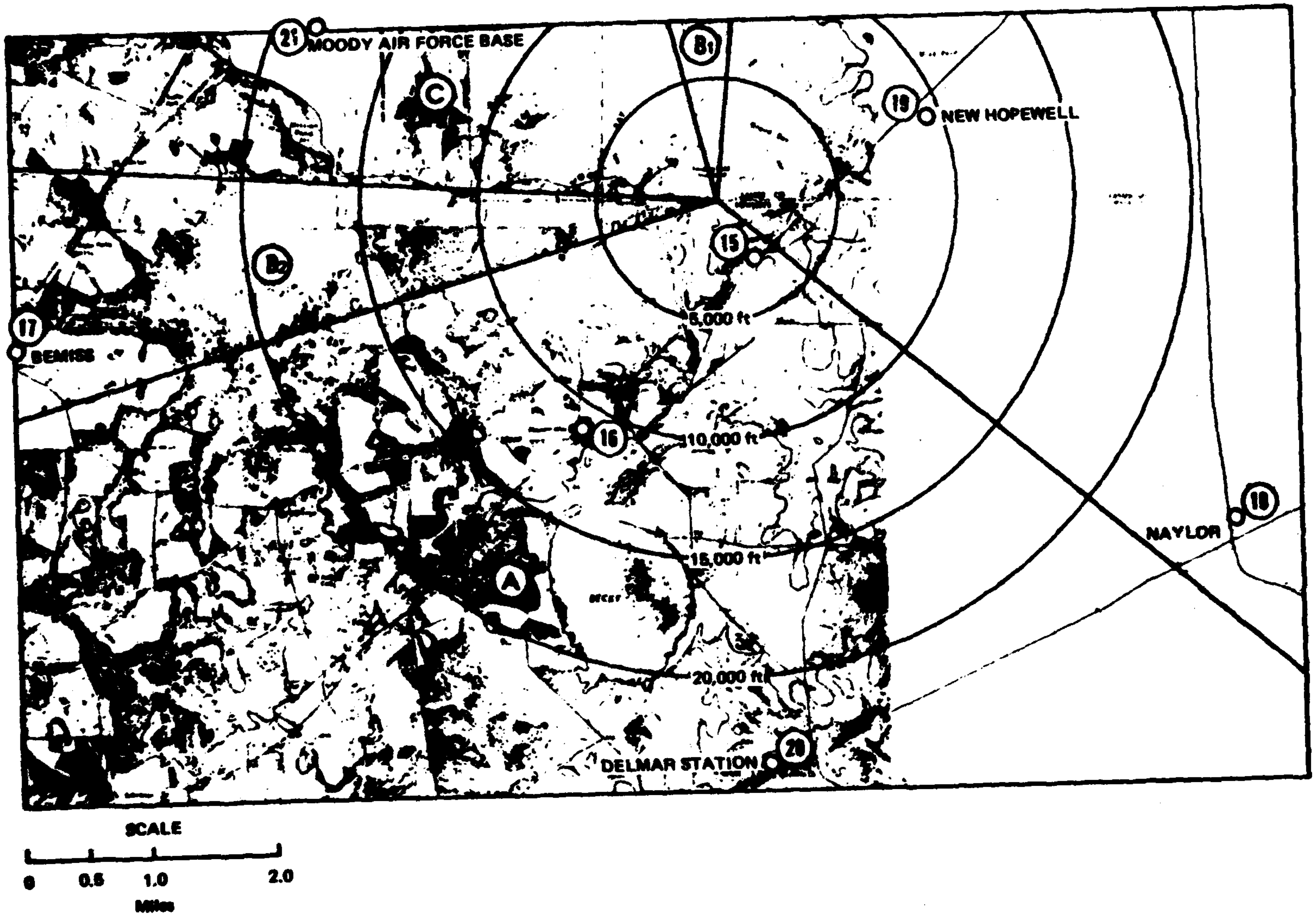


FIGURE 4-11 RFR ZONES OF PAVE PAWS AT MOODY AIR FORCE BASE

Table 4-10

CALCULATED VALUES OF GROUND LEVEL RFR AT SELECTED LOCATIONS NEAR MOODY AFB

	Sector	Site	Elevation	R	Elevation Angle	Az	Z	U_a	U_p	E_p
Building near US 221	A_1	15	200	2,800	+0.20	150	60	0.045[a]	2.9	105
Pleasant Way Church	A_1	16	210	11,300	+0.10	210	20	0.0022	0.33	35
Town of Bemiss	B	17	240	30,000	+0.12	259	69	0.000 0056	0.0011	2.0
Naylor School	A_1	18	190	25,500	0	124	54	0.000 38	0.060	15
New Hopewell Church	A_1	19	200	8,500	+0.07	72	2	0.0036	0.50	43
Delmar Station	A_1	20	195	23,500	+0.01	175	15	0.000 43	0.075	16.8
Towers on Moody AFB	C	21	280	18,300	+0.28	295	87	0.000 0030	0.33	35

U_p = peak power density (mW/cm^2)
U_a = average power density (mW/cm^2)
E_p = peak electric field intensity (V/m)
R = range (ft)
Az = azimuth (deg)
Z = relative azimuth (deg)

Radar base elevation = 190 ft
Radar face elevation = 245 ft
Boresight azimuths = 70 and 190 deg
Scan limit azimuths = 10 and 250 deg
Surveillance beam elevation angle = 3 deg
Surveillance duty cycle = 15%

[a]This value doubled by beam overlap.

discussion and conclusions presented in Section 4.1.1.2.1.2.1 are applicable here.

In the absence of attenuation due to foliage, the highest calculated average power density for ground-level exposure in nearby population centers are 0.045 mW/cm^2 at the building near U.S. Highway 221 (2,800 ft from the radar). The values at the New Hopewell Church (8,500 ft) and the Pleasant Way Church (11,300 ft) would be 0.0036 and 0.0022 mW/cm^2, respectively. The values at the towers near Moody AFB (18,300 ft), Delmar Station (23,500 ft), the Naylor School (25,000 ft), and the Town of Bemis (27,000 ft) would all be less than 0.001 mW/cm^2. At the building near U.S. Highway 221, the pulse power density would be 2.9 mW/cm^2; the values at all of the other locations above would be less than 1 mW/cm^2. The maximum values of pulse and average power density at the 1,000-ft radius of the exclusion fence and at the locations of closest possible public approach would be the same as those for the Robins AFB site.

The entire discussion of RFR bioeffects presented in Section 4.1.1.2.5 et seq. is applicable to the Moody AFB site. Accordingly, it is most unlikely that chronic exposure at the levels of RFR from use of the alternative site would be hazardous to human health.

4.2.1.3 Electromagnetic Environment

4.2.1.3.1 The Addition to the Environment. The PAVE PAWS radar that would be constructed at Moody AFB is identical to that designed for Robins AFB. Its addition to the electromagnetic environment has been discussed in Section 4.1.1.3.1.

4.2.1.3.2 The Effects of PAVE PAWS on Systems. The description presented in Section 4.1.1.3.2 for Robins AFB applies as well to Moody AFB.

4.2.1.3.2.1 Effects on Telecommunication, Radionavigation, and Radiolocation Systems. In general, the effects of a PAVE PAWS radar at Moody AFB would be the same as those of a PAVE PAWS radar at Robins AFB. The differences are only in the locations of the potential systems at or near the two bases. Thus, Section 4.1.1.3.2.1, written principally with regard to Robins AFB, generally applies as well to Moody AFB. In particular, the material on radar altimeters, air navigation systems, air-ground communications, the Amateur Radio Service, point-to-point microwave, and high-power effects was either specifically written to include Moody AFB or was sufficiently general that it applies to either base.

The statement that interference generally would not be likely with land mobile radio applies. We know of no situation at Moody AFB equivalent to the Georgia Power Company's repeaters in front of the SEPP site at Robins AFB.

A PAVE PAWS at Moody AFB would probably produce even fewer instances of interference with TV than one at Robins AFB--principally because of the low population density in the immediate vicinity in front of the radar. The receiving antennas for the Jones Intercable (Moody) cable TV system, near the top of the base's 165-ft water tower, apparently would be in line of sight of the back of SEPP over the trees. Although this would be unlikely to produce interference with the cable TV system, filters could be installed if problems arose.

4.2.1.3.2.2 Effects on Pacemakers, Electroexplosive Devices, and Fuel Handling. The paragraphs on these "hazard effects" in Section 4.1.1.3.2.2 were written to include both Robins AFB and Moody AFB, and so no additional material is included here.

4.2.1.4 Plants and Animals

The airborne and ground-level power densities outside the SEPP exclusion fence would be essentially the same at Moody AFB as at Robins AFB. Therefore, the discussion and conclusions in Section 4.1.1.4 apply equally to both sites.

4.2.2 Biophysical Impacts

4.2.2.1 Plants and Animals

The construction of SEPP within the proposed 10-acre site at Moody AFB would not adversely affect the natural environment.

Construction of the proposed perimeter road and fence around the 60-acre safety zone surrounding the radar facility would not affect any federal or state listed endangered or threatened species, any champion size trees, or any unique or critical habitats. However, if SEPP were located in a more southeasterly position, further study would be required. The 60-acre site would then fall near a sighting of two gopher tortoise burrows. The gopher tortoise (*Gopherus polyphemus*) is a threatened species in Georgia. Populations of this species are scattered throughout the Coastal Plain of the southeastern United States, especially in Georgia and north Florida. Other species associated with the gopher tortoise burrows include the Eastern indigo snake (*Drymarchon corais couperi*) and the gopher frog (*Rana capito aesopus*). These protected species could also be affected if major alterations of the habitat were to occur.

Additionally, if the site were positioned southeast of the proposed location, part of the 60-acre safety zone would fall within a small wetland area, which would need to be examined for the presence of federal or state listed endangered or threatened plant species.

No significant negative impacts to the fauna and flora of Moody AFB due to activities associated with SEPP operation are anticipated.

4.2.2.2 Air and Noise

4.2.2.2.1 Air. At peak construction activity, 100 workers would be commuting to the SEPP site by way of Moody AFB or directly from Highway 221. In comparison to the daily automobile emissions generated by 3,500 employees at the base, incremental emissions are likely to have an insignificant effect on local air quality.

If two pieces of each type of construction equipment identified in Table 4-1 were to be operated continuously during each work day of the first year of the 24-month construction period, related emissions would constitute less than 5% of total pollutant emissions generated annually on Moody AFB, except for nitrogen oxides emissions, which would constitute 17%. Some additional particulate dust would also be created during earth movement activities.

During SEPP operation, both personnel commuting to the site as well as testing and maintenance of the diesel generators would create additional air pollutants. Assuming that three 3,000-kW diesel generators are run a maximum of 15 hr/month (unless required as the main power source), on an annual basis, the power plant would increase Moody AFB emissions by 0.8% (carbon monoxide), 3.6% (nitrogen oxides), and 6.4% (sulfur oxides). Because Moody AFB is in an AQCR that is in attainment of federal air quality standards and because air quality levels at the nearest monitoring stations are well below federal and state standards, the incremental emissions from SEPP are not likely to cause regional air quality to exceed permissible levels, nor to severely degrade air quality at the Okefenokee Wilderness Area 50 miles to the east.

4.2.2.2.2 Noise. The potential noise impacts of SEPP at Moody AFB would be the same as at Robins AFB (see Section 4.1.2.2.2).

Thirty-five structures, including residential buildings, are within a 2-mile radius of the SEPP site. The closest building is about 3,000 ft to the southeast at the edge of Highway 221; most of the others are across the highway. Construction noise may be barely audible at the nearest building and would probably not be distinguishable from other sounds. Any persons using Dudley's Hammock Natural Area or Grand Bay Hunting Area during peak construction activity would be aware of the sounds of large earth moving or installation equipment and might be annoyed, although not harmed, by them.

During SEPP operation, traffic along Highway 221 and along the access road between the highway and the site would increase. The sounds from a maximum of 260 cars daily could affect residents who live along the highway and are accustomed to lower volumes of traffic.

4.2.2.3 Water

4.2.2.3.1 Hydrology. The existing water supply for Moody AFB is drawn from 11 wells in the Hawthorne Formation, a limestone aquifer whose depth ranges from 100 to 1,600 ft. Water withdrawal in the past decade

has caused the local groundwater table (fed by surface waters) to fall 4 ft.

SEPP water requirements would be supplied by a new well at the site, approximately 2 miles from the present wells on Moody AFB. This well is not expected to have a detrimental effect on the aquifer.

4.2.2.3.2 Water Quality. No detailed information is available on the depth of the aquifer underlying the proposed site. Soil test borings conducted prior to construction would indicate the depth to local groundwater; if groundwater were encountered at shallow levels, some contamination could occur during construction.

Wastewater from SEPP would have to be routed to the base sewage disposal plant 4.5 miles from the site or be handled by a small package plant at the site. A septic system could not be used because of local drainage conditions.

The Moody AFB sewage treatment plant has a maximum daily capacity of 750,000 gallons; average daily flow is approximately one-third of capacity (Eiseman, 1982). Connecting to the base disposal system for treatment of the less than 10,000 gpd of SEPP wastewater would be feasible, assuming the wastewater could be piped some distance for hook-up to the wastewater collection beneath the base.

4.2.2.4 Land and Minerals

4.2.2.4.1 Geology. The topography of the region around Moody AFB is gently sloping coastal plain, including swamplands and marshy flats. The proposed SEPP site is a cleared area that was formerly a runway for the base. There is no evidence in the immediate vicinity of the runway of any erosion or bank cutting from increased runoff due to lack of vegetation. The dirt roads and trails in the area all appear to be stable. SEPP is not likely to adversely affect the local geological pattern.

4.2.2.4.2 Soils. Construction activities can alter a drainage pattern, which in turn leads to increased runoff, gullying, and soil loss. Careful planning, providing adequate gutters and culverts, and reseeding would eliminate any potential damage to the soil at the proposed SEPP site. The region's relatively level topography acts as a safety factor in this regard.

Preparing the foundation for the radar facility might require soil compaction and stabilization. Any experience gained in the design and construction of the main base runways, as well as the older runway at the proposed SEPP site, should be useful information for the construction contractor if the radar is installed at Moody AFB.

4.2.2.4.3 Minerals. Construction and operation of SEPP will not preclude future mining activity because there are no known mineral occurrences in Lanier or Lowndes counties.

4.2.2.5 Natural Disasters

4.2.2.5.1 Earthquakes. Only two earthquakes of slight intensity (on the modified Mercalli scale) have occurred in the southern Coastal Plain region in the last 150 years, so a major earthquake is not apt to occur during the lifetime of the SEPP project. The Air Force's construction contractor will design the SEPP facilities to withstand seismic activity typical of south central Georgia (Hassett, 1982).

4.2.2.5.2 Fire. The thickly wooded areas surrounding the SEPP site represent a potential fire hazard, although the perimeter fence and road corridor would serve as a fire break. The safety zone between the security and hazard fence would be grassland; no trees exist in that area at the present time. Thus, a fire starting outside the security area would probably not affect the radar. Some fire prevention measures (e.g., CO_2 hose system and ceiling sprinklers) would be built into SEPP to preclude a fire affecting the interior of the radar installation or power plant.

4.2.2.5.3 Flood. The eastern edge of Moody AFB floods during periods of prolonged rainfall due to overflow from Grand Bay. The proposed SEPP site is encircled by Grand Bay to the north; therefore, it may be necessary to provide adequate drainage at the site to assure that flooding would not occur.

4.2.2.5.4 Storm. Although a severe storm, such as a tornado, could damage SEPP, its destruction would not cause additional incremental damage to the biophysical environment beyond the damage caused by the storm.

4.2.3 Socioeconomic Impacts

4.2.3.1 Employment

Employment in the ROI would be affected by the direct jobs created to construct and operate SEPP, as well as those indirectly generated by personal spending and procurement during construction and operation. The level of direct employment and spending during construction and operation is described in Section 4.1.3.1.

Construction workers would spend an estimated $3.0 million in the ROI during the 2.5-yr construction period. Construction companies would spend another $3.2 million on goods and services. This spending is expected to generate 40 new jobs in the service and trade sectors. However, because the peak construction activity will last less than 1 yr and the national economy, particularly the construction sector, is depressed, local business people are expected to resist hiring new staff and seek greater productivity from their present staff.

The operational work force is expected to spend $2.4 million per year in the ROI. This, plus $3.1 million in annual procurement, would generate demand for about 80 new positions in the service and trade

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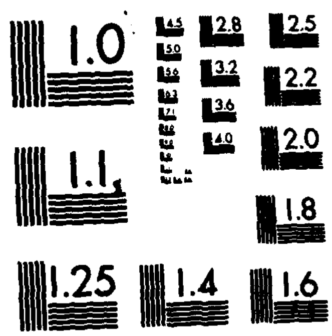

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

sectors of the ROI's economy. Given the permanence of the SEPP work force, many of the 80 jobs are likely to be filled. SEPP operation would reduce unemployment in the ROI in 1985 by 0.2%.

4.2.3.2 Population

It is assumed that most of the construction work force would be hired locally. Those from outside the region would either commute from their present residence or temporarily relocate (without family) in the ROI. Because the influx of Air Force personnel during operation would far exceed the number of construction workers who might relocate, and because the Air Force workers would be accompanied by their dependents and stay in the region for an extended period of time, they would be the primary source of population change.

By 1985, the Air Force operational work force would consist of 263 persons--220 SEPP military, 14 SEPP civilians, and 29 base operation and support. Assuming that the civilians are hired locally, and applying the average family size for the military assigned to Moody AFB, the total population increase would be about 590. Of the 590, 540 are expected to reside in Lowndes County, or 0.7% of the projected 1985 population of the county. This would increase the projected annual growth rate from 2.3% to 2.7% during the buildup period.

The influx of Air Force personnel is not expected to cause secondary population growth in the ROI. In June 1982, 2,050 people in the ROI were unemployed; the less than 100 secondary jobs could be absorbed by the local labor force.

Both the anticipated rate and absolute amount of population growth are small and unlikely to cause significant adverse effects. Subsequent analyses address the ability of particular elements of the infrastructure (e.g., housing, educational facilities) to accommodate the expected increase.

4.2.3.3 Income

Changes in total personal income in the ROI would result directly from salaries of contractor and Air Force personnel and indirectly from spending for personal items, procurement, and construction. During the construction period about $3.2 million in personal income would be created. SEPP operation would generate $6.4 million in personal income annually, which is about 1.3% more than is expected in 1985 if SEPP were not built.

4.2.3.4 Housing

In 1984 and 1985, 249 Air Force households are expected to seek housing in the ROI. The 220 SEPP military personnel include: 16 officers, 7 E-8s and 9s, 190 E-4s to E-7s, and 7 E-1s to E-3s. On the basis of the projected manpower levels at Moody AFB (see Table 3-18), base housing would be at capacity in 1984 and 1985, as it is currently

(FY 82). Although many families may register on the waiting list for military housing and may ultimately be placed, it is assumed, as the worst case, that all families would seek off-base housing.

On the basis of the present distribution of Moody AFB military personnel, 91% of the PAVE PAWS work force (or 227 personnel) would seek housing in Lowndes County. On average, about 14 are likely to seek homes to own and 213 would want rentals (Gillis, 1981, 1982). This represents 0.1% of the portion of the projected 1985 housing stock that is owned and 1.7% of the portion that is rented.

The significance of potential impacts caused by this demand cannot be assessed accurately because of turbulence in the housing industry. Even if the poor market conditions of July 1982 prevail in 1984 and 1985, however, incoming personnel are likely to find housing.

Units for sale across the price range are plentiful, and those with the means to buy should be successful. Rentals are not as readily available. The present vacancy rate is estimated to be less than 5%, and the Air Force demand could push it to about 3%. This would create an extremely tight rental market.

The housing in the ROI is among the most affordable in the United States; nonetheless, the lower ranking enlisted personnel may have to pay more than they desire for housing. The greatest problem may be encountered by any of the 7 E-1 to E-3s who have families.

In summary, if the housing market in 1984-1985 is healthy, as in the years before 1980, it will adequately accommodate SEPP personnel. If the more difficult conditions of July 1982 prevail, Air Force families will find housing but may be forced to contend with higher prices, lower quality, and longer distances to commute.

Part of the construction work force would reside in motels and hotels in the ROI. This would include up to 20 Raytheon employees and perhaps a dozen or more other workers. They can easily be accommodated in the 2,000 hotel and motel rooms in Lowndes County.

4.2.3.5 Education

Assuming that the 249 SEPP and related personnel would follow a residential pattern similar to that of the current base personnel, 227 would choose to live in Lowndes County. On the basis of the current student to Air Force personnel ratio of 0.45 in Lowndes County, about 100 school-age children would accompany the SEPP personnel who would live in Lowndes County.

About 66% of the students of Air Force families in Lowndes County currently attend schools in the Lowndes County School District; the balance are enrolled in schools in the Valdosta City School District. Thus, 66 additional students are expected to attend Lowndes County schools and 34 to attend Valdosta schools. Sufficient capacity

currently exists in all schools in each district to accommodate these additional students. Enrollment is projected to remain stable in the Valdosta schools and to decline in the Lowndes County schools over the 2-yr period when these new students would be arriving. Officials of both school districts believe that their schools would be able to accommodate these new students.

4.2.3.6 Community Facilities and Services

Valdosta officials do not foresee any problems in meeting the public service and facility needs of SEPP personnel who would reside within their service area.

Georgia Power Company would supply power required to operate SEPP. Representatives of the company (1982) believe that generating capacity would be adequate to meet the needs of SEPP without adversely affecting the provision of power to other users.

4.2.3.7 Land Use

Some people living close to SEPP may be concerned about potential adverse biological effects. However, fewer than 30 residences are within the first 2 miles of the scan sector. Because of the agricultural zoning and use and the distance to urban centers and areas of residential growth, additional urban development in this 2-mile band is unlikely in the foreseeable future.

Within the scan sector sparsely populated agricultural areas extend 5 miles west to the development along Bemiss Road (the primary road between Valdosta and Moody AFB), 9 miles southwest to Valdosta, and 5 miles southeast to Naylor (population 288). The nearest industrial and commercial land is in Valdosta. Consequently, land use that might affect or be affected by SEPP is not likely to be developed. However, if such an event becomes probable, mitigating efforts described in Section 4.1.3.7 are available.

4.2.3.8 Aesthetics

The SEPP structure would be located in a clearing within a heavily forested area about 3 miles east of the developed portion of Moody AFB. The SEPP building would protrude about 55 to 65 ft above the surrounding forest, but be visible only from large areas that are not forested. This includes Banks Lake (3 miles north), some buildings on Moody AFB (3 miles northwest), and perhaps from parts of Grand Bay. It should not be visible from Highway 221 or other areas proximate to the site because of dense forestation.

Because of the rural character of the area, the SEPP structure would not be functionally compatible with its surroundings. However, it would not be a dominant terrain feature because it would be visible only from distant vantage points.

4.2.3.9 Cultural Resources

The proposed construction at Moody AFB will not affect any cultural resources. The only known resources lie entirely outside of the 60-acre safety zone.

4.3 MacDill AFB (Radar Closure)

4.3.1 Biophysical Impacts

The MacDill AFB Space Utilization Board, a subcommittee of the Base Facilities Planning Board, has not yet decided what use will be made of the AN/FSS-7 site when the radar is deactivated (Knudsen, 1982). It is estimated that shutdown will occur in 1986, or as soon as SEPP is operating (Dunstan, 1982).

The FAA currently uses a long-range radar facility and related structures adjacent to the AN/FSS-7 site for office and storage space. Similar use of the AN/FSS-7 buildings would not have any new effects on the biophysical environment. Since the site is fairly close to the main base, a number of alternative uses could be made of the radar dome, operations building, and power plant. As part of the Base Development Plan for MacDill AFB, the golf course currently across the street from the site will be expanded to incorporate land around the AN/FSS-7 (Blonshine, 1982). At present, a Rapid Deployment Force project requiring additional facilities and space is in progress at MacDill AFB. However, until definite plans for using the AN/FSS-7 site are made, potential effects of the radar shutdown on the local biophysical environment cannot be determined.

4.3.2 Socioeconomic Impacts

Two squadrons at MacDill AFB, the 20th Missile Warning Squadron (MWS) and the 2159 Communications Squadron (CS), will be phased out when the SEPP becomes fully operational. The phasedown is planned to begin late in fiscal year (FY) 1986 and to be completed by the middle of calendar year (CY) 1987. Currently assigned to these two squadrons are 66 people (19 officers, 46 enlisted personnel, and 1 civilian), representing about 1% of the total base population of 6,642.

Table 4-11 summarizes the effects of the phaseout of the squadrons on the populations of the affected counties. In each county, squadron personnel and their dependents represent less than 0.01% of the projected population. Approximately 40 off-base housing units, accounting for less than 0.01% of the total housing, would become available when these personnel depart. The increase in manpower projected for other units at the base would entirely offset the loss of the radar personnel.

The phasedown would have similarly minor effects on local economic conditions. The base contributes income to the surrounding communities in the form of wages and salaries paid to the base personnel that are spent locally, and local expenditures by the base for food, supplies and

Table 4-11

MACDILL AFB: PROJECTED POPULATION REDUCTION BY PLACE OF RESIDENCE

	Manpower Reduction	Associated Dependents	Total Population Decrease	1985 Estimated Total Population	Percent Decrease
MacDill AFB	25	30	55	2,325 (excluding) dependents)	1.0 (excluding dependents)
Hillsborough County	32	65	97	715,900	0.01
Pinellas County	6	15	21	819,000	0.002
Other Florida counties	3	0	3	488,300	0.001

Source: SRI International.

equipment, services, and the like. Tables 4-12 and 4-13 summarize the income contributed by the squadrons to the surrounding counties and compare this with the contributions by the base as a whole. The income generated is responsible for the creation of less than 50 jobs, representing less than 0.01% of the total employment in each affected county (see Table 4-14).

In summary, the phaseout of the squadrons would not have significant adverse effects on local socioeconomic conditions.

4.4 Eglin AFB (Radar Closure)

4.4.1 Biophysical Impacts

The Eglin AFB Facilities Planning Board has not made a decision regarding future use of the AN/FPS-85 site when the radar facility is deactivated (Williams, 1982). It is estimated that shutdown will take place in 1987, after the SEPP has been operational for some time (King, 1982).

Until a plan for another use of the abandoned site is designed, potential effects on the local biophysical environment cannot be

Table 4-12

MACDILL AFB: PAYROLL, FY 1982

	MWS and CS Payroll	MacDill AFB (all units) Payroll
Officers	$ 630,500	$120,915,000
Enlisted persons	859,100	
Civilians	20,200	19,503,600
Total	$1,509,800	$140,418,600

Note: All figures rounded to nearest $100.

Sources: Hayden (1982); USAF (1982e).

Table 4-13

MACDILL AFB: LOCAL EXPENDITURES BY COUNTY, FY 1982

	MWS and CS Expenditures	MacDill AFB (all units) Expenditures
Hillsborough County	$61,000	$43,230,600
Pinellas County	4,000	3,189,700
Other Florida counties	32,000	22,374,600
Total	$97,000	$68,974,900

Sources: Dunstan (1982); USAF (1982e).

Table 4-14

MACDILL AFB: EMPLOYMENT REDUCTION BY COUNTY

	Manpower Reduction	Off-Base Multiplier	Employment Reduction	1982 Total Employment	Percent Decrease
Hillsborough County (including MacDill AFB)	59 military 1 civilian	0.66 0.81	40	322,706	0.01
Pinellas County	6 military	0.66	4	279,664	0.001

Sources: USAF (1982f); SRI International.

determined. Maintaining the site as it is so that the computer facilities in place there now can be used for purposes other than analysis of AN/FPS-85 radar data would probably not lead to any new environmental effects. However, removing the existing buildings and equipment and designating the approximately 50-acre site for recreation or nature interpretation would likely result in beneficial effects as the area could be revegetated and would provide additional habitat for animals. On the other hand, developing the site further for an entirely different use that would entail additional structures and more people might have certain adverse impacts on the local biophysical environment.

4.4.2 Socioeconomic Impacts

Three squadrons at Eglin AFB--the 20th MWS, the 2159 CS, and the Air Force Logistics Command (AFLC) Detachment--will be phased out when the SEPP becomes fully operational. The phasedown is expected to commence at the end of FY 1986 and be completed by the end of CY 1987. Currently, there are 388 persons assigned to the three squadrons; this accounts for about 2% of the total base population of 18,189.

The phaseout of the three squadrons and their 388 personnel during FY 87 could reduce the projected county population by 1% (see Table 4-15). The average growth rate in the county population is projected to be 1.7%/yr (see Table 3-33); therefore, during the 9-month phaseout period, population growth would be reduced to an annually adjusted rate of about 0.4%.

Approximately 290 off-base housing units, representing less than 1% of the total housing stock, would become available when these personnel depart. This would not cause significant adverse effects in the housing

Table 4-15

EGLIN AFB: POPULATION REDUCTION BY PLACE OF RESIDENCE FOR 20th MWS, 2159 CS, AND AFLC PERSONNEL

Okaloosa County	Manpower Reduction	Associated Dependents	Total Population Decrease	1987 Estimated Total Population	Percent Decrease
Off-base	288	644	936		
Eglin AFB (on-base)	100	225	325		
Total	388	869	1,261	123,400	1.0%

Source: SRI International.

market; however, the precise effects, whether they be positive or negative, would be a function of the market conditions in 1987.

Effects of the phasedown on local economic conditions would also be minor. The squadrons contribute income to Okaloosa County in the form of personnel wages and salaries spent locally and local expenditures by the squadrons for supplies, equipment, services, and the like. Table 4-16 summarizes the squadrons' payroll and local expenditures for FY 1982. Income generated by the three squadrons is responsible for the creation of about 260 jobs, or about 0.6% of the total civilian jobs in the county (see Table 4-17). An estimated 45 positions would be vacated by working spouses of Air Force employees; thus, the potential reduction in employment would be about 220 (0.5% of total civilian employment). However, because regional employment is expected to grow at about the same rate as the population, the annual increase in the number of jobs during the phasedown would be reduced to about 1% (if effects were to occur in a 1-yr period). Nevertheless, effects on employment are likely to continue for several months after the phasedown is completed.

In population, employment, and other parameters of economic health, the absolute change caused by the phasedown would be relatively minor. Also, the effects would be spread over a long period of gradual change. The phasedown is expected to occur over a 9-month period and, to the extent that personnel lost to attrition are not replaced, the phaseout may be effectively longer.

Table 4-16

EGLIN AFB: PAYROLL[a] AND LOCAL EXPENDITURES OF 20th MWS AND 2159 CS PERSONNEL, FY 1982

	Amount
Payroll	$7,326,400
Local expenditures	509,900
Total	$7,836,300

[a]Figures are based on a 10-month average and rounded to the closest $100.

Source: Ortman and Kusik (1982).

Table 4-17

EGLIN AFB: EMPLOYMENT REDUCTION IN OKALOOSA COUNTY FROM THE 20th MWS, 2159 CS, AND AFLC

	Manpower Reduction	Off-Base Multiplier	Employment Reduction	Estimated 1987 Civlian Employment	Percent Decrease
Military	344	0.66	263	42,100	0.6
Civilian	44	0.81			

Source: SRI International.

4.5 No Action or Postponement of Action

The no-action alternative is to not construct and operate the PAVE PAWS facility at either Robins AFB or Moody AFB. If this alternative is pursued, all the impacts of construction and operation of the radar will be avoided.

Not operating SEPP also means foregoing the national security and defense benefits to be gained by its operation. If SEPP is not operated, radars that it is scheduled to replace will continue to operate. The PAVE PAWS radar, based on phased-array technology, can track many targets concurrently, and can do so more accurately and at long range. In addition, it can simultaneously search for and track objects, thus permitting detection and accurate counting of all attacking sea-launched ballistic missiles. This superior ability to warn and to characterize missile attacks would be sacrificed if SEPP were not operated.

No alternative methods of radar surveillance and tracking other than continued operation of obsolete radars will be available in the foreseeable future to substitute for PAVE PAWS.

Postponing action would involve delaying full-scale operation of SEPP. Neither the characteristics of PAVE PAWS operation nor the affected characteristics of the environment would change with the passage of time. Therefore, postponement would only delay occurrence of the impacts discussed in Chapter 4, but not alter them. Further, no apparent environmental benefit would be gained by postponement. Although complete and detailed knowledge of biological effects is not available, current information does not indicate any significant risk and is being used to provide safeguards, such as exclusions. On the other hand, a lengthy postponement would increase the risk to the security of the United States.

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Appendix A

RADAR AND ANTENNA CHARACTERISTICS

A.1 Introduction

The Southeast PAVE PAWS radar system (SEPP), to be installed at Robins or Moody AFB, Georgia, is very similar to systems now in operation at Beale AFB, California, and Otis ANG Base, Massachusetts. The principal difference is that the power radiated by SEPP is three times as large as that of the existing systems.

A radar operates by transmitting a pulse of electromagnetic energy and then waiting to receive energy reflected back to it from some object (target) illuminated by the pulse. The radar interprets the time interval between the transmitted pulse and the return as a measure of the distance from the radar to the target.

It is highly advantageous for a radar to concentrate its transmitted energy (and to limit its receiving capability) in a relatively narrow beam. A narrower beam permits greater certainty regarding the direction in which the energy was sent and from which it returned. A narrower beam also conserves available energy by concentrating it into a single direction; also, it permits reception of weaker returns from a particular direction by discriminating against electromagnetic noise or extraneous, interfering signals that may arrive from other directions.

Radar has long used paraboloid reflectors, or dishes, to form beams in the same manner that the silvered reflector of an automobile headlight forms a beam from the light generated by the lamp's filament. To move the beam, the radar dish and the radiating element are typically rotated at a particular fixed rate to sweep the beam past a given azimuth every second or so. The need for mechanical motion limits the speed of scanning in such radars.

A.2 Formation of the Beam

PAVE PAWS differs from a conventional radar in several respects. Both of its faces are covered with many small fixed radiating elements, each of which is driven by its own transmitter under the control of a computer. The computer can adjust the phase (timing) of the transmitted (and received) energy of each radiating element relative to that of the others to form a very narrow beam of energy. Each complete antenna face is known as a phased array. Because it has no moving mechanical parts, the phased array can switch its beam from one part of the sky to another within a few microseconds, unhampered by mechanical inertia. (To perform their basic functions, radar systems operate in very brief units of time. The conventional unit is the microsecond, i.e., one-millionth of a second; it is to be distinguished from the millisecond, which is one thousand times longer.) Thus, instead of sweeping, the PAVE PAWS beam can be thought of as probing from any given direction (azimuth and

elevation) to any other within its limits. Each of the two faces of the PAVE PAWS radar covers an azimuthal sector 120 deg wide. Together they can make observations in a 240-deg sector from 10 deg (i.e., 10 deg east of north) clockwise to 250 deg (i.e., 20 deg south of west). Neither face is capable of radiating power more than 25% of the time.

The primary function of this radar is to detect sea-launched missiles at very great distances. To perform this function, the radar must radiate a very strong, well-focused beam of electromagnetic energy and must provide a corresponding sophistication in receiving any echo that is returned from a distant missile. These considerations force the system designer to use a very large antenna and provide a strong motivation for refining the design so that most of the power is concentrated in the main beam. The PAVE PAWS antenna meets these criteria, concentrating about 77% of the available power in the main beam (Shackford, 1982).

A general idea of the beam-forming process is provided by Figure A-1 (Hansen, 1964). Near the antenna face, the energy moves forward in an almost circular column of roughly constant diameter. At a greater distance, the energy expands as a cone with an included angle of 3.0 deg with its apex at the center of the antenna face. A slender conical beam of this kind is commonly referred to as a pencil beam. The cone and cylinder intersect at a distance of about 1,850 ft. The following sections provided a more detailed description of the beam.

A.2.1 Beam Structure

Each of the two faces of PAVE PAWS forms a single and separate main beam with associated sidelobes, as indicated in Figure A-1. The sidelobes result from the radar's inability to concentrate absolutely all of the energy in the main beam. The location of the first sidelobe is well known, and its intensity is never greater than 0.025* that of the main beam. The locations of the second and third sidelobes are also known; their respective intensities are never greater than 0.013 and 0.008 that of the main beam. The large number of higher order (and very minor) sidelobes are distributed at various, almost random, angles. They have power densities no greater than 0.001 of that of the main beam; some have as little as 0.00003 of the power density of the main beam.

A.2.2 Scanning Characteristics

To perform the surveillance function, the pencil beam formed by the antenna is scanned continuously. Using a complex time-sharing technique, the radar generates a surveillance fence (scan) at a minimum elevation

*The system specification for this parameter is 0.020. The relative sidelobe intensities used in this document are intentionally increased to obtain conservative (overstated) values of RFR.

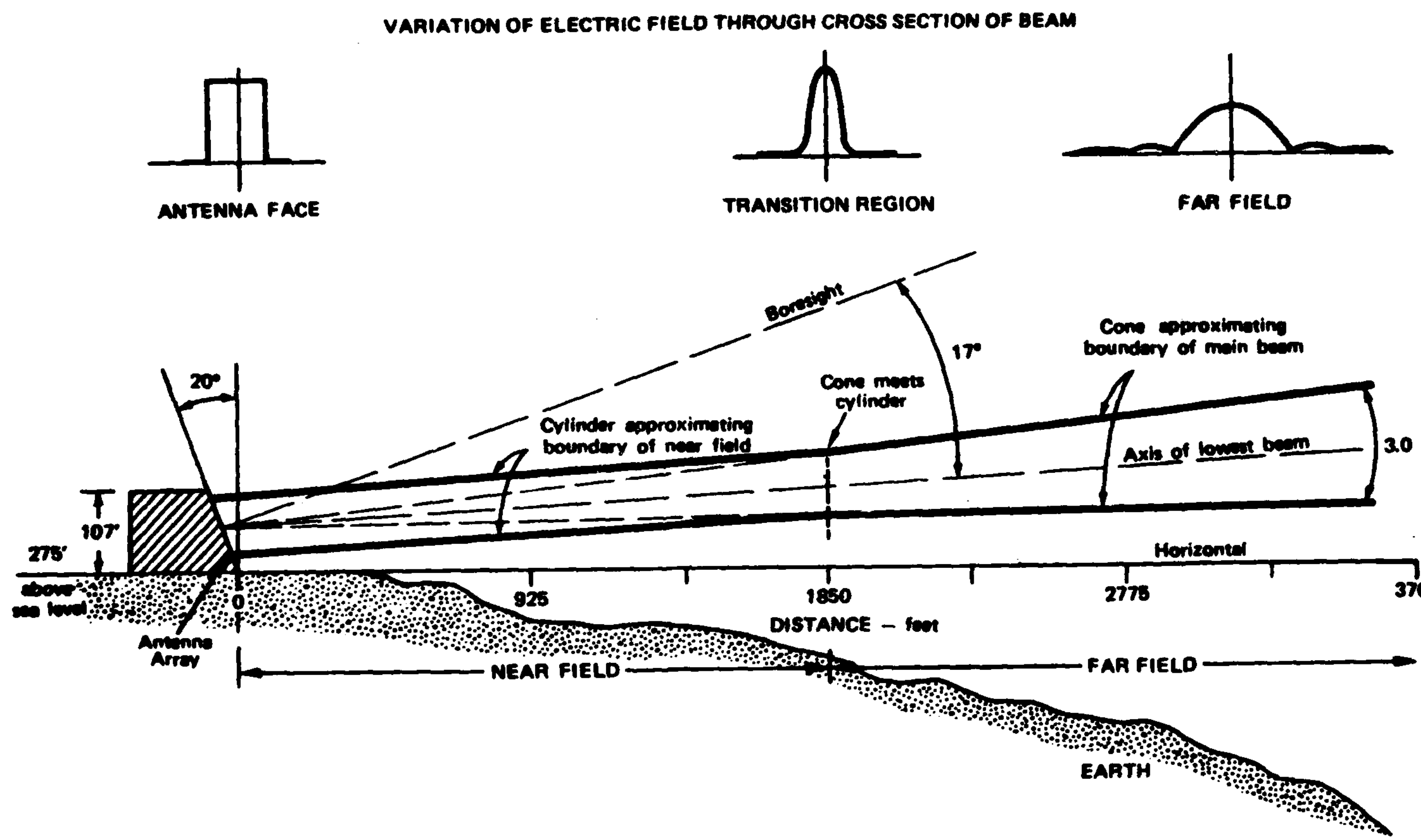


FIGURE A-1 FORMATION OF PAVE PAWS RADAR BEAM

of 3 deg above horizontal and covering 240 deg in azimuth; it also executes special satellite searches and numerous target tracks, all within as short a time as about 45 seconds. This great versatility is made possible by the electronic beam scanning characteristics of the phased array, which can change beam locations from any direction in the coverage volume to any other direction within tens of microseconds.

A.2.3 Scanning Limits

The PAVE PAWS antenna system is designed to prevent the transmitted beam from being directed below a minimum elevation angle or in any other direction outside their normal angular coverage. The minimum normal elevation angle is 3 deg; redundant automatic interlocks are provided to inhibit transmission of power in the improbable event of some system failure that might attempt to direct the beams outside the normal coverage defined by +3-deg to +85-deg elevation and ±60-deg azimuth on either face. These interlocks are contained in the Tactical Software, the Radar Control Computer Software, and in the Beam Steering Unit hardware.

A.2.4 Grating Lobes

If the antenna element spacing in a phased array such as PAVE PAWS exceeds half a wavelength, additional lobes (known as grating lobes) can appear in the antenna radiation pattern. They are formed by the radiation from the elements adding in phase and forming additional wavefronts in directions for which the relative path lengths are integral multiples of one wavelength. When circumstances permit, grating lobes first form parallel to the array face (i.e., at 90 deg from each boresight direction), at the highest operating frequency of the radar, and when each main beam is at the maximum scan angle. Unless suppressed in some way (for example, by the directional pattern of the individual radiating elements), the grating lobes could have an intensity equal to that of the main beam. In PAVE PAWS (and all practical phased array systems), the element spacing is chosen to prevent the formation of grating lobes.

For a phased array with the equilateral triangular element distribution used by PAVE PAWS, the maximum scan angle for a radiation pattern free of grating lobes is given by the following expression for a generally horizontal scan (Kahrilas, 1976):

$$S_m = \arc\sin\left(\frac{L}{d \cos 30 \text{ deg}} - 1\right)$$

where

S_m = maximum scan angle from array normal (deg)

d = interelement spacing = 40.85 (cm)

L = radiation wavelength at 450 MHz = 66.7 (cm).

Evaluating this expression gives a maximum scan angle from the array normal of 62.5 deg. No grating lobes will be formed because the maximum azimuth scan angle is 60 deg.

Similar analyses have been performed for other scan directions to verify that grating lobes will not be formed for any scan direction. For example, the PAVE PAWS system must scan upward through 65 deg to reach the elevation of +85 deg. However, the governing equation for vertical scanning is

$$S_m = \arc\sin\left(\frac{L}{d/2} - 1\right) .$$

This equation is not satisfied by any real angle; therefore, grating lobes cannot form in vertical scanning.

A.2.5 Subarrays

An important advantage of phased array radar systems is that several of the elements can fail without seriously degrading the overall performance. An undesirable consequence of this feature is that considerable vigilance is required to detect and correct failure or malfunction of the individual elements.

The design of the PAVE PAWS radar includes diagnostic subsystems to solve this problem. Each face of the array is divided into a set of subarrays, with each subarray consisting of an equal number of transmitting/receiving elements and thus being capable of forming a beam; however, the resulting beams are necessarily much broader and less intense than those of the complete array. The systems installed at Otis ANG Base and Beale AFB use 56 subarrays, each consisting of 32 elements. The disposition of the subarrays for these existing systems is shown in Figure A-2. SEPP will use 168 subarrays, each consisting of 32 elements, in a pattern yet to be determined. Section B.4 of Appendix B demonstrates that the effects of subarray testing will be inconsequential, regardless of the pattern chosen.

About 200 ft in front of each face and about 12 ft above local ground level, a test antenna is located. It consists of a standard crossed dipole element (like all those on the array face) mounted on a circular metal disk about 3 ft in diameter. This antenna is connected through coaxial cables to monitoring equipment housed in the radar building and can both transmit and receive.

The receiving capabilities of the radar are tested by occasionally sending 50-microsecond pulses from the test antenna. The receiving capability of any single element--or group of elements--can be evaluated by comparing the response with a precalibrated reference, which includes the path lengths and angles involved.

The test antenna is also used to monitor the functioning of the transmitting components of the radar. In this case, the test antenna

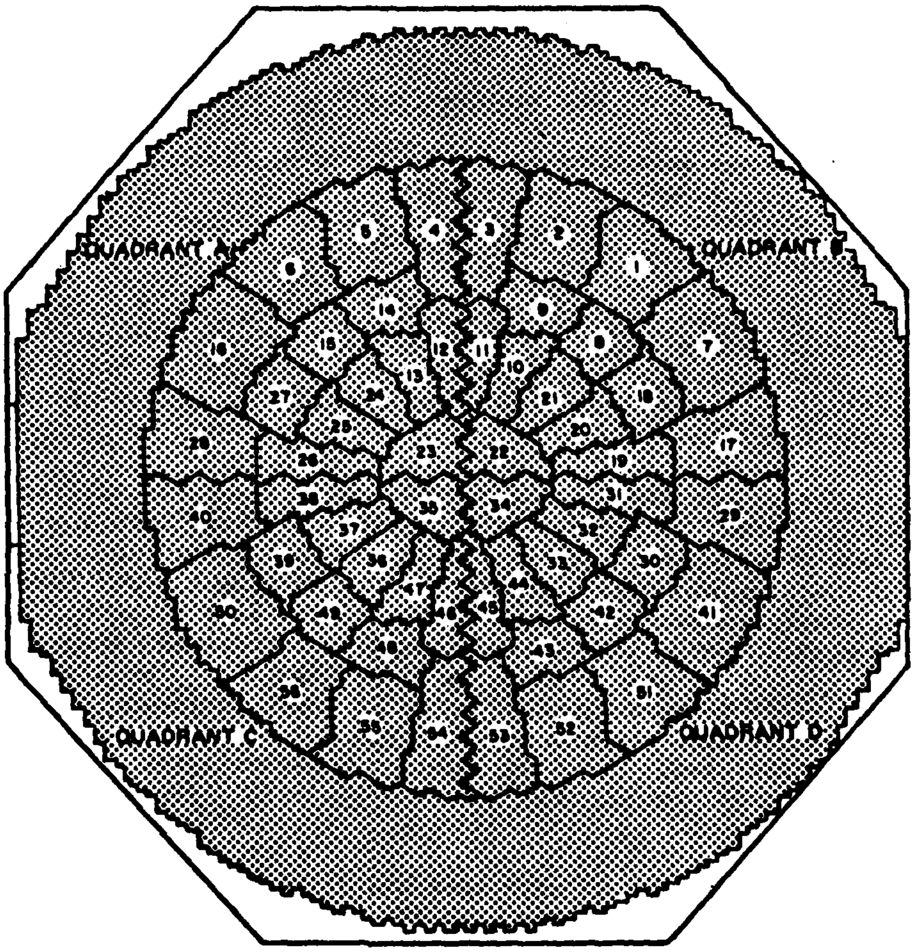


FIGURE A-2 SUBARRAY POSITIONS FOR EXISTING SYSTEMS

functions in a receiving mode. Once every 30 s, each subarray delivers a 50-microsecond pulse that is focused on the test antenna. Again, the response is compared with a standard that includes the particular geometrical arrangement of the subarray being tested.

The test antenna is approximately level with the lowest element of the 102-ft array. It is therefore below the center of any possible subarray. Consequently, the test beam strikes the ground within a few hundred feet of the array face.

Most of the power radiated for such tests will strike the ground. However, some of it will be scattered and will add to the diffuse time-averaged power density associated with the higher order sidelobes. Appendix B shows that the contribution of such testing is a negligible part of the total.

A.3 Transmitted Pulse Codes

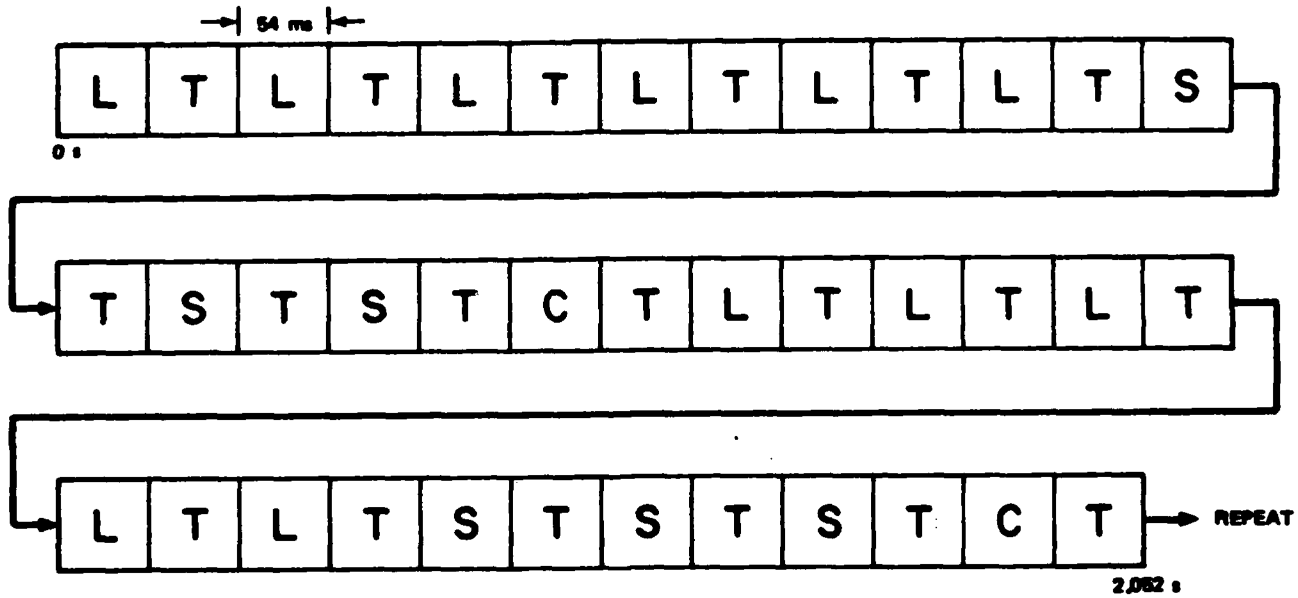
Pulses transmitted by the radar are allocated to specific tasks in accordance with the radar energy requirements of those tasks and the priority allocated to each. In task scheduling, time is divided into radar intervals, or "resources," that are expected to last 65 ms. Successive resources can be used for surveillance, tracking, or calibration and monitoring of performance and interference. Time is shared between the various functions of the radar. Details of the allocation of SEPP resources have not yet been determined; however, the allocation is expected to be similar to that used in the existing systems at Otis ANG Base and Beale AFB. A template of the nominal resource allocation for the existing systems is given in Figure A-3. The principal difference is the 65- versus 54-ms duration of each resource. This difference stems from the increased range (4,000 versus 3,000 miles) of the SEPP and is reflected in a reduction in duty cycle from 18% to 15%.

During normal operation, about 95% of the resources are used for surveillance; the remainder are used for calibration and monitoring of performance and interference. The percentage of the resources used for surveillance is reduced to about 50 during a heavy tracking assignment.

A.3.1 Long-Range Surveillance

Both faces of the radar search simultaneously, and their beams are synchronized. The beam normally remains at a 3-deg elevation angle, but can be moved up to 10 deg in discrete increments for operational reasons. The beam is switched from one azimuth to another in a complicated but fixed manner during a scan sequence, hitting each spot in the 120-deg sector about 7 to 24 times.* (The spots toward the edges of the sector

*These numbers are subject to moderate change as part of final system optimization.



L = LONG-RANGE SURVEILLANCE
S = SHORT-RANGE SURVEILLANCE
T = TRACK OR VERIFICATION
C = CALIBRATION AND PERFORMANCE MONITORING (EVERY 18th OR 20th RESOURCE, ALTERNATELY)

FIGURE A-3 NOMINAL RADAR RESOURCE TEMPLATE FOR EXISTING SYSTEMS

are hit more often than those toward the center.) In normal operation, the sequence takes about 45 s;* then it repeats itself. (During this time, the radar is also conducting its short-range surveillance and tracking.) In enhanced or reduced surveillance, the sequence takes a shorter or a longer time, but the same spots are still hit in the same order.

A.3.2 Short-Range Surveillance

For detecting objects at distances less than about 1,400 nautical miles, it is advantageous to shorten the pulse length and decrease the interval between pulses. Such operation is referred to as the short-range surveillance mode. In this mode, the elevation angle of the beam is the same as for long-range surveillance, and both faces continue to search simultaneously and in synchronism and at the same relative position.

A.3.3 Tracking

The two faces track independently, according to the number and locations of objects needing to be tracked. The beam is limited to a minimum elevation angle of 3 deg and a maximum of 85 deg. Tracking is time-shared with the surveillance functions; when fewer objects must be tracked, more of the resources are available for surveillance. Tracking pulses are never sent simultaneously from both faces.

A.3.4 Pulse Groups and Duty Cycles

Each 65-ms radar resource is divided into transmit and receive (listen) periods. Figure A-4a shows how both two-pulse clusters and three-pulse clusters are used in long-range surveillance in the existing PAVE PAWS systems. The beam position is moved only slightly (about 2 deg) between successive pulses of a particular cluster. However, each successive cluster may be widely separated in azimuthal angle from the last.

In short-range surveillance, the existing systems break up the resource into three 13.5-ms sections, each with a cluster of three 0.3-ms pulses, and a fourth segment with a single 3-ms pulse (see Figure A-4b). Surveillance pulses are chirped (varied continuously in frequency) over a 100-kHz band.

Figure A-5 shows four patterns for breaking the existing 54-ms resource into transmit and receive periods for tracking. Patterns are selected according to the distance to the target. More than one pulse may be sent in a transmit period. Any number of pulses up to eight can occur in the transmit period of the resources labeled T_1, T_2, and

*This number is subject to moderate change as part of final system optimization.

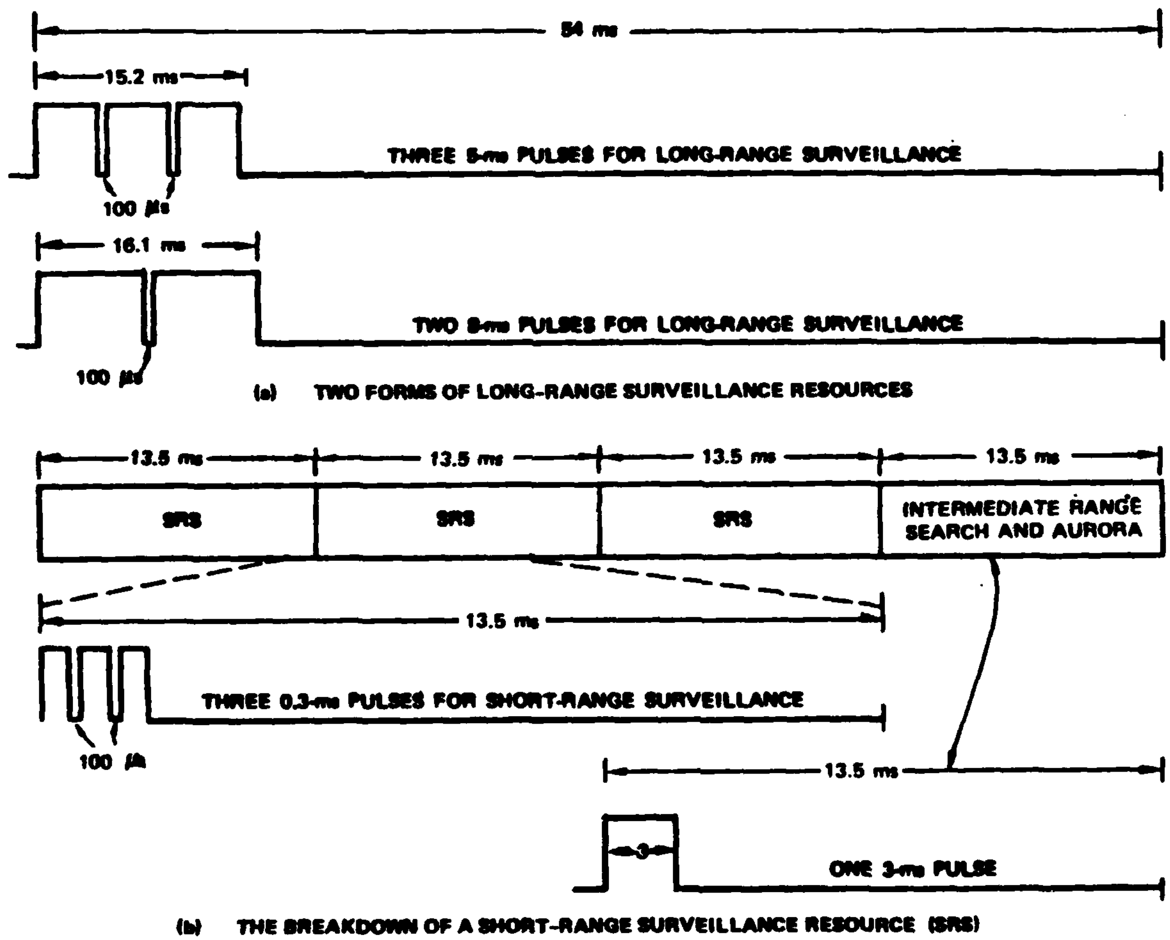


FIGURE A-4 LONG-RANGE AND SHORT-RANGE SURVEILLANCE RESOURCES FOR EXISTING SYSTEMS

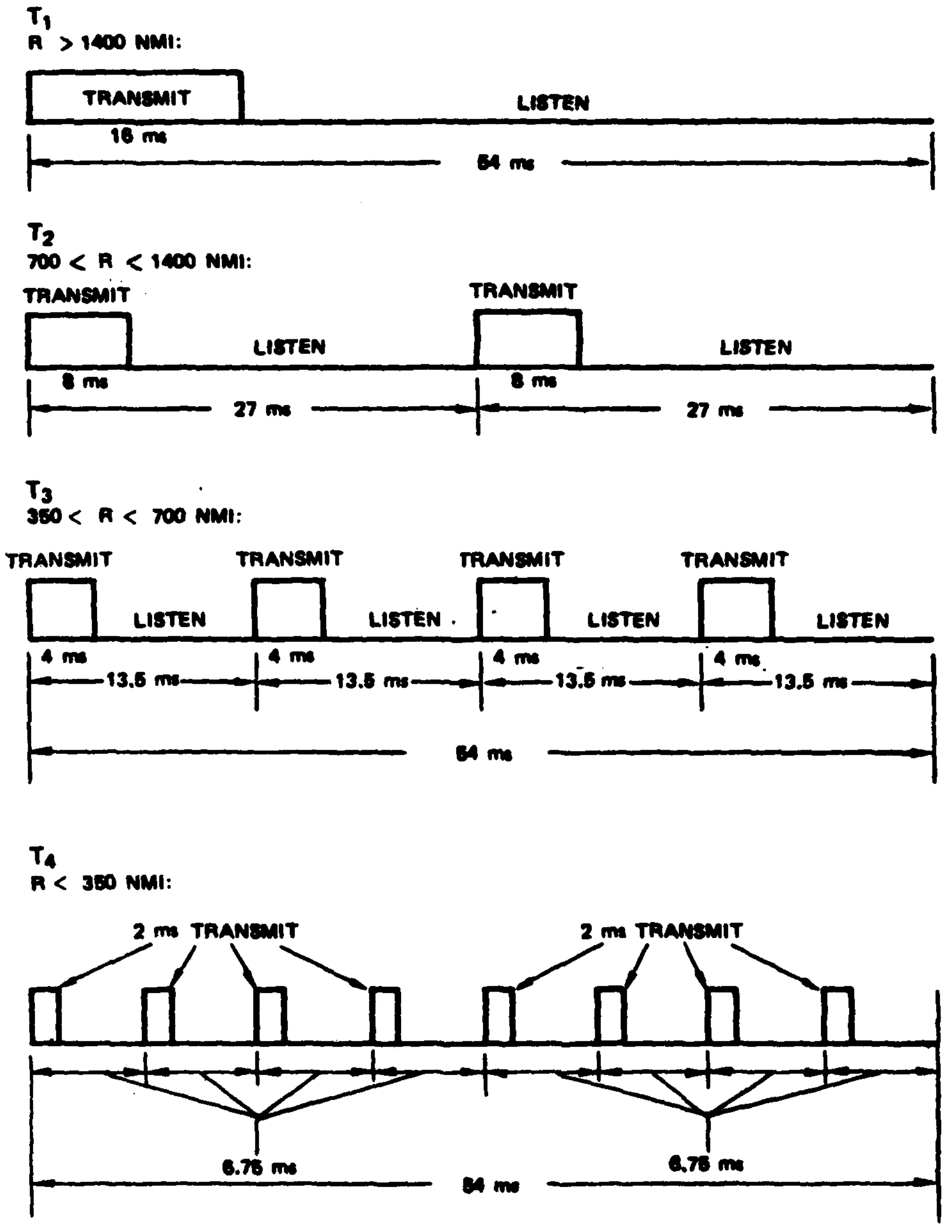


FIGURE A-5 TRACK RESOURCES FOR EXISTING SYSTEMS

T_3; only one pulse can occur in the 2-ms transmit periods of T_4. Any part of the transmit period may also be empty, reducing the duty cycle of a single track resource to less than its maximum possible value. Track pulses are chirped over a frequency band of 1 MHz, and the available pulse widths range from 16 to 0.25 ms. The allocation of track resources for SEPP will be similar to that shown in Figure A-5.

Various algorithms control the tracking pulses. Among the constraints are:

- Track pulses must not be transmitted simultaneously on both faces.

- During any 1-s interval, the duty cycle for all radar activities on either face may not exceed 25%.

The latter constraint is imposed by the limitations on the radar's ability to cool the transmitter modules. The normal duty cycle for each face is about 15%. The 25% duty cycle is expected to occur only under the most stressful circumstances (for example, during a missile attack), when one face would be used heavily for tracking targets. If that were to occur, the duty cycle for the other face would have to be reduced to about 11%.

A.3.5 Frequency Switching

The PAVE PAWS radar transmits on the 24 channels illustrated in Table A-1, generally switching frequency between one pulse and the next. Although the pulses of the two- or three-pulse clusters of the long-range surveillance resources differ in frequency by only about 200 kHz, every other surveillance or tracking pulse is shifted at least 3.6 MHz from the preceding pulse. A different frequency is used for each short-range search pulse in the same resource and also for each tracking pulse in the same resource. Also, no frequency can be used in a long-range surveillance resource that has been used in the immediately preceding track resource.

The 24 center frequencies, spaced at 1.2-MHz intervals from 420 to 450 MHz, are interleaved in three sets of eight, as shown in Table A-1. The radar selects increasingly higher frequencies from set A, recycling through the set A frequencies for about 31 resources (approximately 2 s). The radar then proceeds similarly with the set B frequencies, and then the set C frequencies. Thus, the normal jump from one pulse to the next is 3 x 1.2 MHz = 3.6 MHz. (Smaller frequency shifts are used within the pulse clusters of the long-range surveillance resource mode, and larger shifts occur when the radar jumps from one frequency set to the next.) It takes about 2.56 s for a signal to propagate to the moon and back; the sequential use of the three frequency sets is such that the radar's receiving system is tuned for frequencies from sets B and C when echoes of set A frequencies from the moon are finally returned to earth. The same holds true, of course, for the other two frequency sets, so the radar is never confused by an echo from the moon.

Table A-1

PAVE PAWS FREQUENCIES

Channel Number	Center Frequency (MHz)			Frequency Set		
1	421.3			A		
2		422.5			B	
3			423.7			C
4	424.9			A		
5		426.1			B	
6			427.3			C
7	428.5			A		
8		429.6			B	
9			430.8			C
10	432.0			A		
11		433.2			B	
12			434.4			C
13	435.6			A		
14		436.8			B	
15			438.0			C
16	439.2			A		
17		440.4			B	
18			441.5			C
19	442.7			A		
20		443.9			B	
21			445.1			C
22	446.3			A		
23		447.5			B	
24			448.7			C

The radar operator can choose to delete any of the allotted frequencies from those available for use. In addition, frequencies are deleted automatically if an auxiliary receiver at the PAVE PAWS building detects undue interference on any of them. Thus, PAVE PAWS switches from one frequency to another at least as often as every resource period; the exact frequency usage cannot be predicted because it depends on the number and locations of the objects being tracked.

A.4 System Parameters

The PAVE PAWS radar characteristics described in this appendix were obtained from the PAVE PAWS program office, Hanscom AFB, Massachusetts (Shackford, 1982). These characteristics are listed in Table A-2.

Under normal circumstances, each face of the radar emits power about 15% of the time; that is, the duty cycle averages 15%. Ordinarily nearly all of the resources are used for maintaining the routine surveillance fence. Under very exceptional circumstances of heavy tracking

Table A-2

CHARACTERISTICS OF SOUTHEAST PAVE PAWS SYSTEM

System Characteristic	Value
Frequency (MHz)	420-450
Number of elements	5,376
Wavelength[a] (ft)/(cm)	2.26/69.0
Peak power[b] (kW)	1,750
Duty cycle (%)	
Scan mode minimum (normal)	7 (15)
Track mode max (normal)	18 (-)
Total max (normal)	25 (15)
Active array diameter (ft)/(cm)	102.5/3,125
Antenna gain[a] (ratio) compared to non-directional antenna at 435 MHz	20,500
Beam width at half power density (deg)	1.3
Main beam null (deg off-axis)	1.5
First sidelobe--max (deg off-axis)	2.1
First sidelobe relative power density--max (ratio)[c]	0.025
First sidelobe null (deg off-axis)	2.8
Second sidelobe relative power density--max (ratio)[c]	0.013
Second sidelobe null (deg off-axis)	4.1
Third sidelobe relative power density--max (ratio)[c]	0.008
Third sidelobe null (deg off-axis)	5.4
Other sidelobes maximum power density--relative to main beam (ratio)	0.001
Angle of antenna face relative to vertical (deg)	20
Minimum elevation angle of beam (deg)	+3
Scan sector (deg), (north = 0 deg, east = 90 deg, etc.)	10 to 250
Percentage of power in main beam	77
First sidelobe (%)	7
Second sidelobe (%)	3
Third sidelobe (%)	1
All other sidelobes (%)	12

[a]At the midband frequency, 435 MHz.

[b]Consistent with other sections of this document, we refer to the root-mean-square (rms) value of the pulse when present.

[c]The system specification calls for a relative first sidelobe level no larger than 0.020. During normal operation all three sidelobes are expected to have levels below those indicated here.

assignment, the duty cycle of either face can be increased to 25%; under these conditions, the duty cycle of the other face is necessarily reduced to 11%. The principal significance of these statements with respect to the RFR field at ground level is that the duty cycle governs the time-averaged power density. Power densities corresponding to 15% duty cycle are used in all subsequent calculations because they are relevant to long-term cumulative exposure.

In no case does the 25% duty cycle increase the peak intensity; the short-term average power density is nowhere increased by as much as 50% during enhanced tracking at 25% duty cycle.

A.5 References

Hansen, R. C., Microwave Scanning Antennas, Vol. 1: Apertures, Academic Press, New York and London (1964).

Kahrilas, P. J., Electronic Scanning Radar Systems (ESRS) Design Handbook, Artech House, Inc., Denham, Massachusetts (1976).

Shackford, R. F., personal communication (July 1982).

Appendix B

CALCULATION OF RADIOFREQUENCY RADIATION INTENSITIES

B.1 Introduction

This appendix presents an analytic procedure for calculating the intensity of radiofrequency radiation (RFR) in the vicinity of the Southeast PAVE PAWS radar (SEPP). Data obtained from the PAVE PAWS Program Office, Hanscom AFB, Massachusetts, the National Academy of Sciences (NAS, 1979), and the Raytheon Company (Rawlinson, 1977) are combined with information available in textbooks and technical journals to develop mathematical expressions that permit calculating RFR intensity at specific locations. The first seven sections of this appendix are devoted to analysis; the remaining sections use the resulting analytic expressions to determine values for the peak electric field, peak power density, and average power density at selected points in the vicinity of the radar. Power densities at the center of the beam are also calculated to provide a basis for estimating their effect on personnel and electronic systems in aircraft and on birds.

This analytic technique allows predictions that are quite accurate in free space. However, the results are affected by the presence of the ground and of objects such as trees, buildings, and power lines. In the real world, the ground terrain is irregular, and objects such as trees, buildings, and other structures are randomly distributed. When they block the line of sight to the antenna, they tend to absorb, reflect, and scatter the field. In such circumstances, the field strength is lower than it would be in free space. In other situations, the power reflected from the earth or other objects adds to that propagated directly, thus increasing the intensity of radiation. Under circumstances relevant to PAVE PAWS, the electric field strength is rarely as much as doubled in this way. Field enhancement of this kind is much more important in calculations of maximum electric field strengths and power densities than of time-averaged power densities.

B.2 Conditions and Assumptions

A large antenna that is many wavelengths in diameter produces a radiation field that is concentrated in a small volume of space and is commonly referred to as a narrow or pencil beam. The PAVE PAWS antenna falls into this class. The major characteristics of such a pencil beam (Hansen, 1976) are determined by the following features of the array:

(1) Shape
(2) Diameter in wavelengths
(3) Power distribution
(4) Overall efficiency.

The mathematical description of the complete field produced by large antennas is very complicated. Therefore, approximate expressions have been developed to facilitate calculation.

The following conditions and assumptions are applied:

(1) The main beam and its first three sidelobes are considered to have circular symmetry. Actually, the width of the beam increases as the scan limits are approached.

(2) The relative intensities of the first, second, and third sidelobes are taken from data provided by the PAVE PAWS Program Office. They are substantially higher than those associated with a uniform, constant-phase circular aperture.

(3) The transition between near-field and far-field conditions occurs at 1,850 ft, which is defined herein as $0.40\ D^2/L$, rather than the conventional $2D^2/L$ (see Section B.2.1), where D is the active array diameter and L is the radiation wavelength.

(4) The maximum possible on-axis power density in the near field is assumed to exist throughout the near-field column.

(5) In most cases the greatest possible instantaneous field strength at any ground location will exist when the antenna main beam is at the azimuth of that location and has the minimum elevation angle of 3 deg above the horizontal plane. All calculations of ground-level field strength are made for the case of a +3-deg beam elevation angle.

(6) The duty cycle for each face is taken as 15%, all of which is devoted to the surveillance fence at 3-deg elevation. This is the normal average duty cycle for the system.

(7) Calculations of RFR field strengths at any distance from SEPP up to 15 miles are based on direct line-of-sight propagation because all other modes of propagation, such as ducting due to temperature inversion, diffraction, or tropospheric scatter or reflection, are weaker (Kerr, 1951; NAS, 1979). Ground-level areas that are shadowed by intervening terrain will be illuminated by the diffraction mode of propagation. The RFR field strengths in such areas will be overestimated because the calculations are based on direct line-of-sight propagation. A factor for the attenuation caused by trees and underbrush, which can be 0.1 or less, is not included.

(8) The calculations are intended to represent realistic estimates rather than precise scientific values. Many approximations are made; therefore, it is expected that the field strength at any given location produced by operation of PAVE

PAWS may be either larger or smaller by a factor of 2 than the calculated value.

The resulting electromagnetic field of the main beam of each face is normally described by dividing it into two regions, the near field and the far field, to which different sets of analytical conditions apply. The boundary between the two regions is not sharply defined; rather, RFR field conditions gradually change with increasing distance from the face of the antenna. It is also necessary to distinguish between regions within or near the main beam and those at angles remote from it. Different approximations apply to the different regions. The regions used are shown in Figure B-1.

The designated azimuth scan limits for both faces are 10 deg to 250 deg, with a difference of 240 deg. Sector A is extended 4 deg on each side from these limits to account for power concentrated in the first three sidelobes. The limit of sector B is set by the angle whose cosine is 0.1, which is 84 deg from the boresight of the nearest face. This choice results in no discontinuity of power density at the boundary with sector C. Depending on future decisions, the actual scan boundaries may be adjusted plus or minus 2 deg from these values.

B.2.1 The Far-Field Region—Peak Power*

The far field exists only in sector A_1; it is defined as a region over which the analytic conditions are constant and the fields vary inversely with distance (i.e., the power density varies inversely with the square of the distance). The distance from the array face beyond which the conventional far field exists is $2D^2/L$. For SEPP, this distance is 9,200 ft. However, far field formulas give good approximations for all distances greater than 1,850 ft.

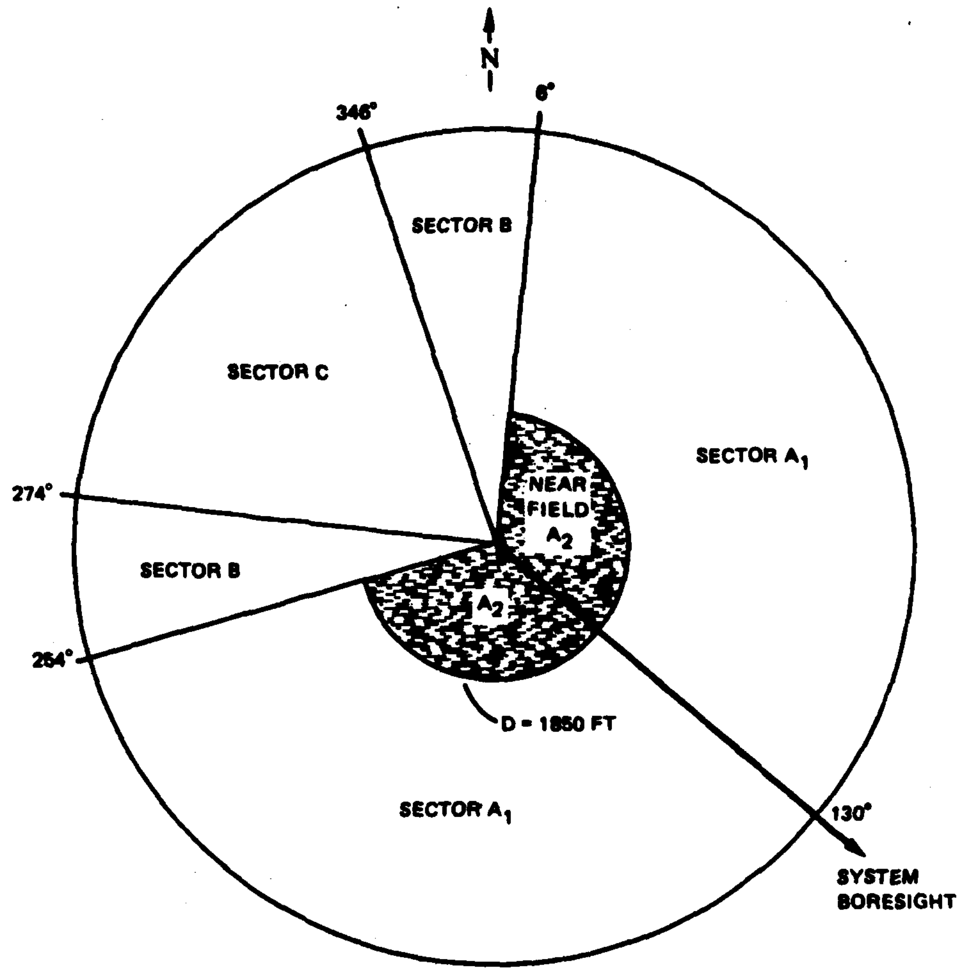
B.2.1.1 The Main Beam

A well-known and generally applicable equation for the power density on the beam axis in the far field region of any antenna is

$$U = PG/4\pi R^2 \qquad (1)$$

where U is the power density, P is the radiated power, G is the antenna gain, and R is the distance; consistent units must be used. For SEPP, P = 1,750 kW and G = 20,500. To obtain results in the desired form of milliwatts/cm^2 when the range is specified in feet, it is necessary to introduce suitable factors. To convert from kilowatts to milliwatts and from square feet to square centimeters, one must multiply by 10^6 and divide by $(30.48)^2 = 929$. Combination of these various terms

*Here, and throughout this document, the terms peak power and pulse power designate the root-mean-square (rms) value of the pulse, when present.



IDENTIFICATION OF SECTORS

FIGURE B-1 SPACE SUBDIVISIONS USED FOR CALCULATION OF RFR

leads to a key result: for the far field, the peak power in the center of the main beam is

$$U_1 = 3.1 \times 10^9/R^2 \quad mW/cm^2 \qquad (2)$$

where R is the distance in feet.

B.2.1.2 The First Three Sidelobes

The main beam of SEPP never strikes the ground. Therefore, power distribution in the various sidelobes must be considered.

System measurements, confirmed by computer modeling (Malowicki, 1981), show that the ratio of the power in the first sidelobe to the power in the main beam at the same distance is not greater than 0.025. The ratios of the power in the second and third sidelobes to the power in the main beam are 0.013 and 0.008, respectively. The power in all other sidelobes is still weaker; its maximum value relative to the main beam is 0.001.

The distribution of power at various angles within the main beam and first three sidelobes is shown in Figure B-2*. Any locations that sometimes fall in the first null (at 1.5 deg) are at other times subject to the higher power density of the first peak at 2.1 deg. Similarly, locations that sometimes fall into the second null (at 2.8 deg) are at other times subject to the higher power density of the second peak at 3.4 deg. Therefore, all calculations of peak sidelobe power use the envelope function shown in heavy line in Figure B-2.

B.2.1.3 Higher Order Sidelobes

All higher order sidelobes tend to be random in nature and are subject to a confirmed limit of 0.001 relative to the main beam. The directivity of each element of the array (Rawlinson, 1977) varies approximately as the cosine of the angle X, which is measured away from a line perpendicular to the face of the array. The angle X is measured in any direction from the boresight axis, which has an elevation of 20 deg. It is desirable to convert this expression to conform to scan azimuth and elevation angles relative to the horizontal. A standard identity from spherical trigonometry shows that, for angles near horizontal, little error will result if X is replaced by Z, the azimuth angle away from the boresight direction of the face. On this basis the maximum value of any higher order sidelobe is represented by $U_2 = (3.1 \times 10^6 \cos Z)/R^2$. This value was derived for far-field conditions; however, as shown later, it is valid also in the near field.

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*The shape of the beam deteriorates somewhat as the direction of the beam is steered away from the boresight axis. In particular, its (horizontal) width almost doubles as the scan limits are approached.

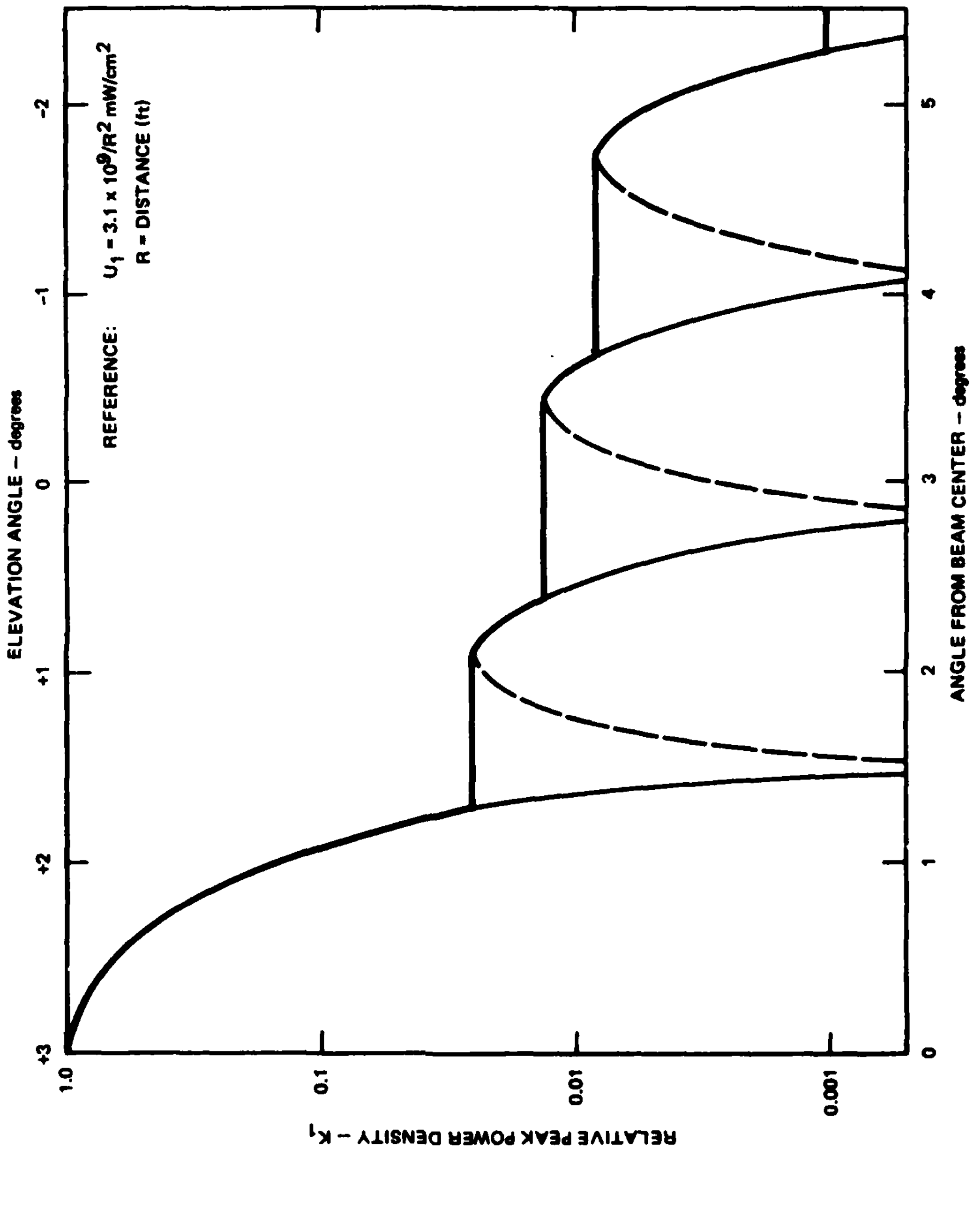

FIGURE B-2 ANTENNA PATTERN FOR FAR FIELD REGION

B.2.2 The Far-Field Region--Average Power

In PAVE PAWS operation, the main beam is pointed in a given direction only for the duration of a single pulse, after which it is pointed in a different direction, with essentially no overlap with the previous location. The mobility of the radar main beam has an averaging effect on the RFR field power density. In other words, it can reduce the effect of the main beam and sidelobes, as well as "fill in" nulls between lobes of the field pattern. The averaging factor will differ depending on whether the area is illuminated by the main beam or by some combination of sidelobes. The averaging factor becomes less important at close ranges, where the diameter of the radiation column is comparable to the distance through which it is swept.

B.2.2.1 Main Beam and First Three Sidelobes

A prime function of the PAVE PAWS system is to maintain a surveillance fence, which is normally at an elevation angle of 3 deg. The 120-deg sector assigned to each face is covered by using 60 beams that are separated by about 2 deg. However, successive beams are never adjacent, and scan sequences and beam locations are not exactly repeated. To evaluate the amount of peak and average power that strikes the ground, one should visualize the process as equivalent to continuous scanning. This procedure is valid, because the average beam increment is small compared to the diameter of the main beam and its sidelobes.

If some object in the far field were raised to a +3-deg elevation, it would be struck with the full power of the main beam, with a peak power density of $U_1 = 3.1 \times 10^9/R^2$. The situation is illustrated in Figure B-3. The corresponding average power density is obtained by combining the duty cycle and the ratio of the beam width to the total scan angle. The duty cycle of the surveillance fence is 0.15, the effective beam width between half-power points is 1.3 deg, and the scan angle is 120 deg. Hence, the main beam contribution to the time-averaged power density for an elevation angle of 3 deg is

$$U_4 = (0.15 \times 1.3/120)U_1 = 1.63 \times 10^{-3}U_1 = 5.0 \times 10^6/R^2 \qquad (3)$$

Points either higher or lower would receive a smaller average exposure because the intensity of the main beam falls to zero at 1.5 deg from the beam axis. Therefore, the variation of the average power density* must

---

*To compensate for deterioration of the beam shape, the duty cycle is increased as the beam direction approaches the scan limits. Thus, equation 3 tends to overstate values near the azimuth boresight and to understate values near the scan limits. The degree of accuracy provided by this average value is within the intended limits of these calculations.

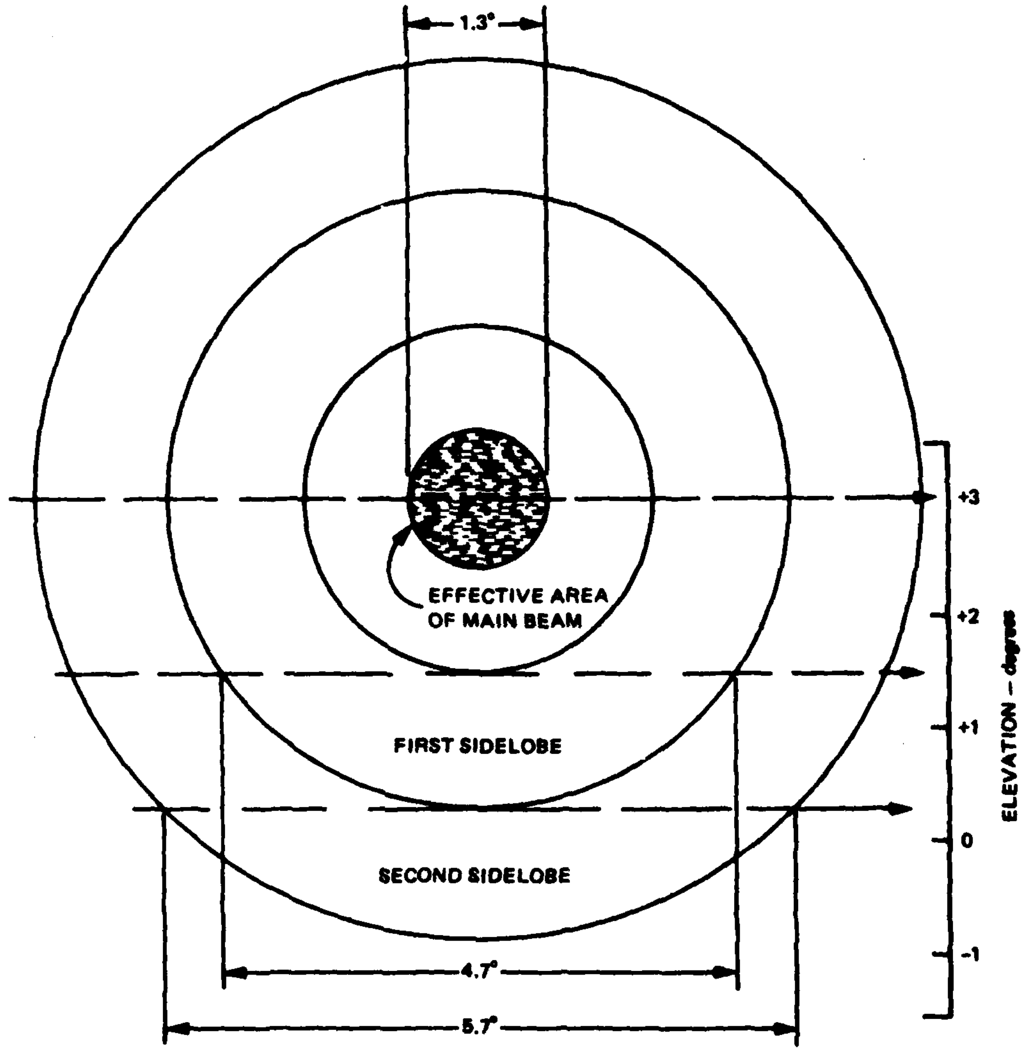

FIGURE B-3 EFFECT OF SCANNING BY MAIN BEAM AND FIRST TWO SIDELOBES

have the same general form as the variation of peak power of the main beam; this variation is shown as the main lobe of Figure B-4.

We next consider a point at an elevation angle of 1.5 deg, which corresponds to the first null of the main beam; it is exposed to the maximum power of the first sidelobe twice per sweep. As shown in Figure B-3, the exposure extends over about 4.7 deg of the 120-deg total. Using the same logic as before and introducing a factor of 2 to account for averaging across the sidelobe and a factor of 0.025 for the sidelobe intensity relative to the main beam, we have

$$U_5 = (0.025 \times 0.15 \times 4.7/120 \times 2)U_1 = 7.3 \times 10^{-5} U_1$$

$$= 0.045\ U_4 = (2.3 \times 10^5)/R^2 \quad . \qquad (4)$$

The average power contributed by the first sidelobe varies slowly as the elevation angle is decreased from 1.5 deg to 1.0 deg, which corresponds to the peak intensity. Both peak and average values fall to zero at an elevation angle of 0.1 deg. Therefore, the first sidelobe contribution must closely approximate the form shown in Figure B-4. It does not fall to zero for elevations within the main beam.

Repetition of this process for the second sidelobe at an elevation angle of 0.1 deg leads to a value

$$U_6 = (0.013 \times 0.15 \times 5.7/120 \times 2)U_1 = 4.6 \times 10^{-5}\ U_1 \qquad (5)$$

$$= 0.029\ U_4 = 1.4 \times 10^5/R^2 \quad .$$

This value, together with others, is plotted in Figure B-4.

For the third sidelobe (not shown in Figure B-3) the same procedure yields

$$U_7 = (0.008 \times 0.15 \times 7.0/120 \times 2)U_1 = 3.5 \times 10^{-5} U_1$$

$$= 0.022\ U_4 = 1.1 \times 10^5/R^2 \quad . \qquad (6)$$

B.2.2.2 <u>Higher Order Sidelobes</u>

As previously noted, the higher order sidelobes are random in nature and have a maximum intensity of 0.001 times that of the main beam. The principle of conservation of energy is used to calculate their time-averaged intensity. Because 88% (Shackford, 1982) of the radiated power goes into the main beam and the first three sidelobes, no more than 12% remains to be distributed in higher order sidelobes.

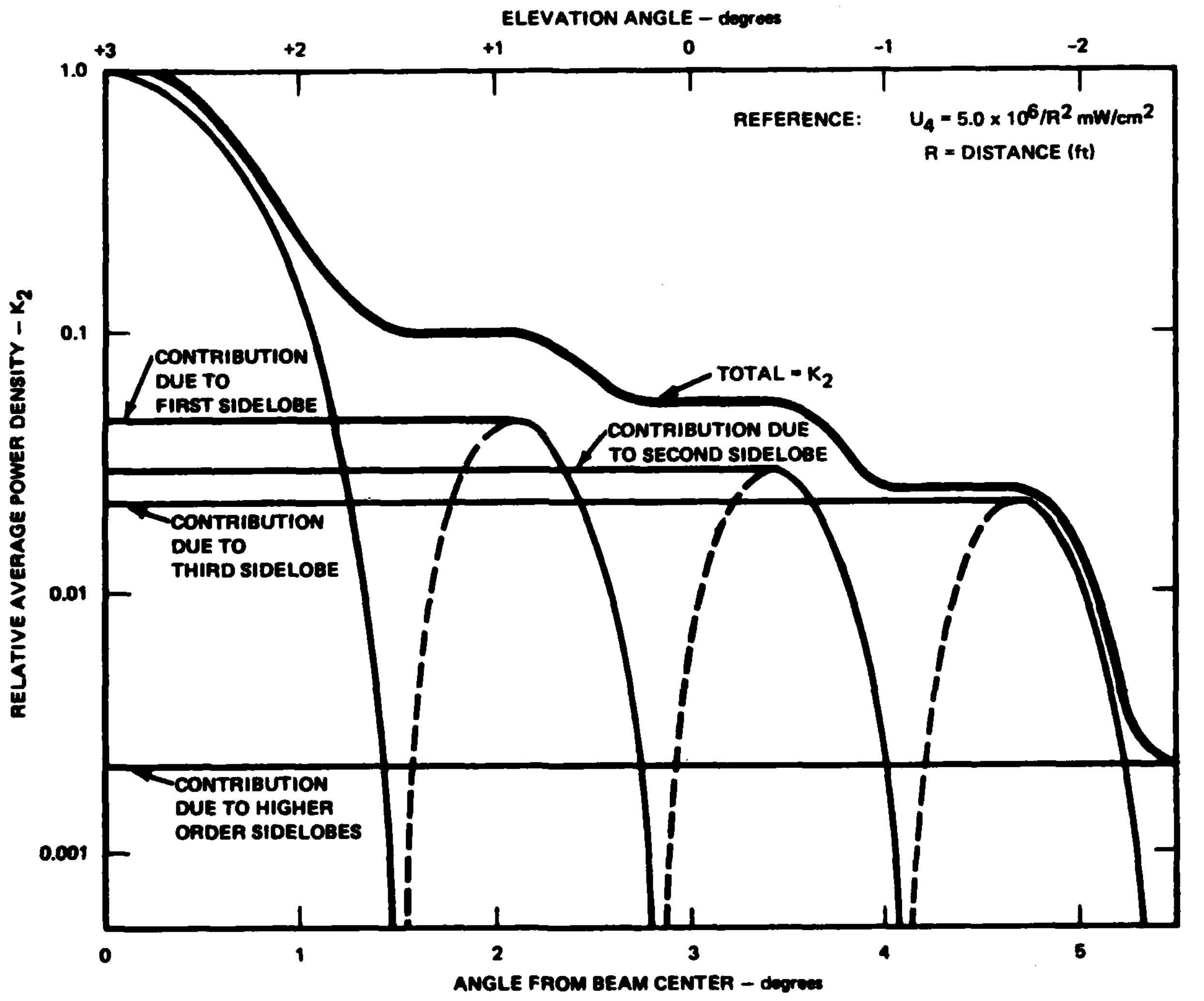

FIGURE B-4 MAIN BEAM AND SIDELOBE CONTRIBUTIONS TO AVERAGE POWER DENSITY

Under normal conditions the maximum PAVE PAWS duty cycle is 15%, and the power radiated from one array face in higher sidelobes is 0.12 x 0.15 x 1,750 kW = 3.15×10^7 mW. This must represent the total time-averaged power of all the higher order sidelobes in all directions. To express this mathematically, we may integrate (sum) over a hemispherical surface by writing

$$3.15 \times 10^7 = \int_0^{90} 2\Pi RU(R\sin X)\, dx \quad . \tag{7}$$

The time-averaged power density from the random high-order sidelobes is again assumed to vary as the cosine of X; that is, $U = U_m \cos X$. On this basis

$$\frac{3.15 \times 10^7}{\Pi R^2} = 2\int_0^{90} U_m \cos X \sin X\, dX = U_m \sin^2 X \Big]_0^{90} = U_m \tag{8}$$

where U_m is the (maximum) time-averaged power density in the boresight direction. Thus, the time-averaged power density due to higher order sidelobes in any direction in the far field is

$$U = (1.0 \times 10^7 \cos X)/R^2 \quad . \tag{9}$$

As a result of the methods used, R is in centimeters; to convert to feet it is necessary to divide by $(30.48)^2$ and obtain

$$U_8 = (1.1 \times 10^4 \cos Z)/R^2 \tag{10}$$

where R is in feet, and the power density is in mW/cm^2. Again, little error results from substituting Z for X.

This value was derived for far-field conditions. However, nothing in the development is so restricted. Therefore, it may be used down to distances that are comparable to the diameter of the array, i.e., about 100 ft. It is additive to the power contributed by the main beam and the first three sidelobes.

Within sector A the cos Z factor in equation 10 varies over a range of about 2:1. However, the total value of U_8 is small compared to the values of U_4, U_5, U_6, and U_7. Thus, the total power is only moderately overstated if cos Z is taken as unity. This procedure permits formation of a single composite curve, which is designated "total" in Figure B-4.

B.2.3 The Near-Field Region--Peak Power

The surface area of the array is given by the formula

$$A = \Pi D^2/4 \quad . \tag{11}$$

The total peak power P radiated must pass through this area. Therefore, the average value of the peak power density near the face of the array is equal to the ratio of these two numbers. In the near field region, the power density varies in a complicated manner. In some locations the fields are very weak; in others the electric field is doubled and the power density is increased by a factor of 4. On this basis, and following Hu (1961), we write

$$U_0 = 4P/A = 16P/\Pi D^2 \quad . \tag{12}$$

Substituting P = 1,750 kW, D = 102.5 ft, and converting units yields

$$U_0 = 910 \text{ mW/cm}^2 \quad . \tag{13}$$

This value is used for the peak power density throughout the cylindrical column that represents the near field. It is in satisfactory agreement with results from computer modeling (Malowicki, 1981).

Equations 2 and 13 give equal values for a distance R = 1,850 ft. This distance is taken as the end of the near field and the effective beginning of the far field.

As previously noted and confirmed by analysis (Hu, 1961), the transition from near field to far field conditions is not abrupt. Thus, the results of the previous analyses can be merged by writing

$$U_3 = \frac{910}{1 + (R/1{,}850)^2} \quad . \tag{14}$$

This single equation adequately represents the peak power density in the center of the main beam at all distances.

B.2.3.1 Near-Field Power at Ground Level

The power density represented by U_0 in the previous section exists only within the circular column of the main beam; ground-level values are much smaller. The peak power density that exists near ground level in the near field has been estimated by using antenna elevation patterns that were generated by computer modeling (Malowicki, 1981) and are reproduced with minor changes in Figure B-5. They have been smoothed within the region of interest to focus attention on the general trend; they correspond to a beam elevation of 3 deg and to an azimuth directly below the boresight direction.

The center of the array face is 53.5 ft above ground level and is 18 ft behind the point where the array face meets the ground. If by accident some individual should walk into the near-field region, the principal risk would be to the head, about 5.5 ft above the ground. Accordingly, the calculations were made as if the center of the radar face was 53.5 - 5.5 = 48 ft above ground. The geometry used in these calculations is shown in Figure B-6.

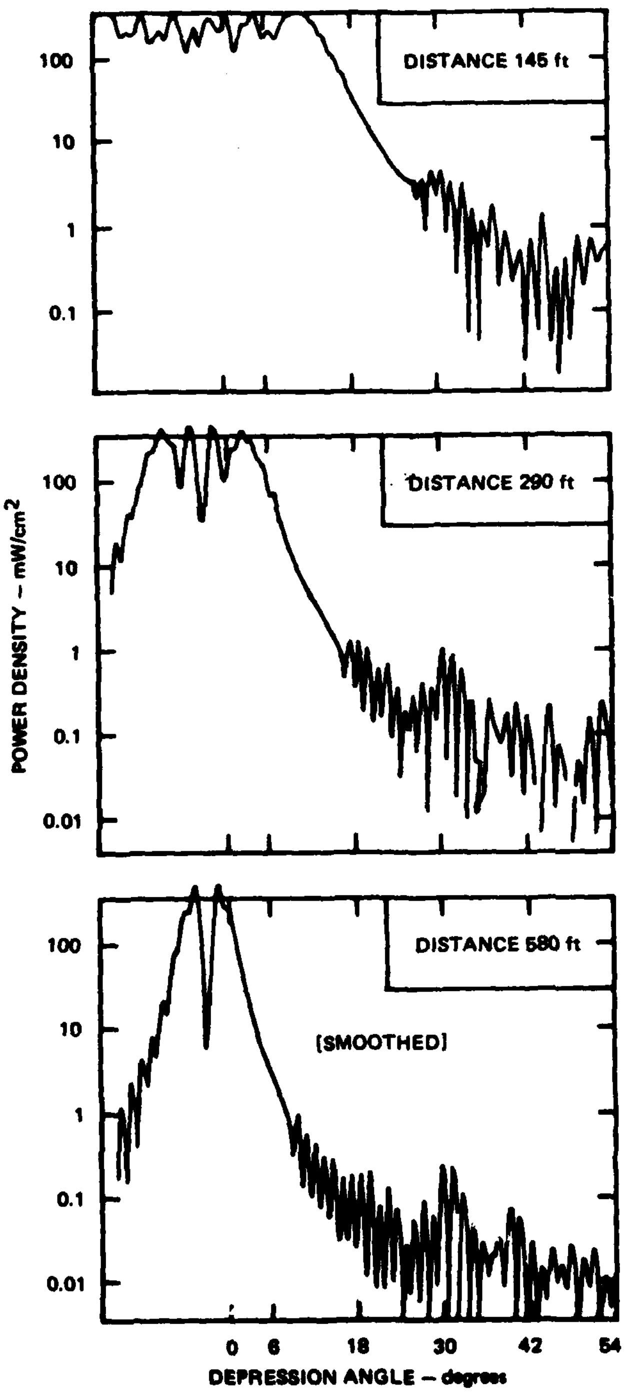

FIGURE B-5 NEAR FIELD ELEVATION PATTERNS

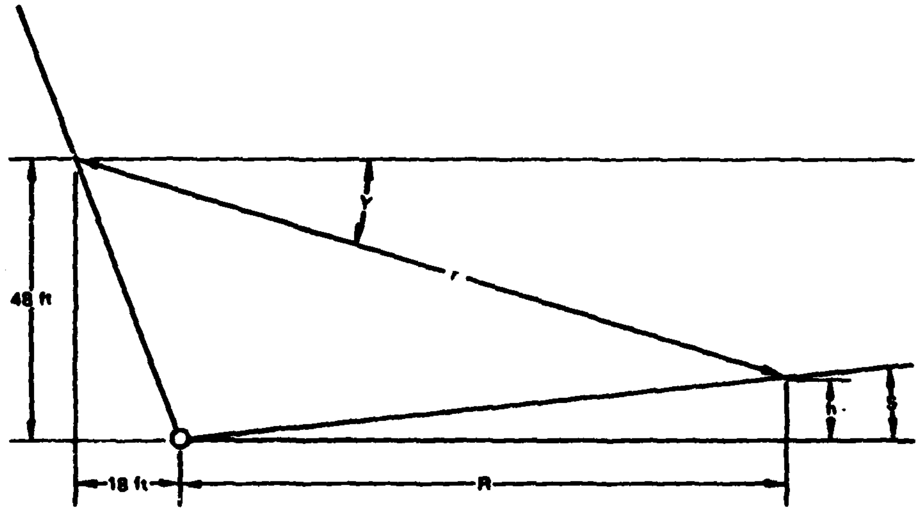

FIGURE B-6 GEOMETRY FOR CALCULATING NEAR FIELD POWER DENSITIES

The following equations apply to Figure B-6:

$$h = R \tan S$$

$$48 = h + r \sin Y$$

$$R = r \cos Y - 18$$

where r, R, and h are in feet, and S and Y are angles in degrees, referred to the horizontal. Simultaneous solution of these equations is not practical, but successive approximation yields the results presented in Table B-1.

Application of the values of R and Y from Table B-1 to the curves of Figure B-5 leads to the set of curves shown in Figure B-7, which apply to ground that slopes either up or down from the level at the base of the radar face. The validity of these curves has been checked by extending them to large distances, where they are in good agreement with values obtained from far-field relationships.

B.2.3.2 The Near-Field Region--Average Power

The expression $U_S = (1.1 \times 10^4 \cos Z)/R^2$ has been shown to represent the time-averaged power density of higher order sidelobes in the far field region. Because of the R^2 term in the denominator, this expression cannot give correct results at extremely small values of R. It has also been shown (see equation 7) that the total time-averaged power in the higher order sidelobes is 3.15×10^7 mW, and that the area of the array face is $\pi(30.48 \times 102.5)^2/4$ cm^2. Therefore, near

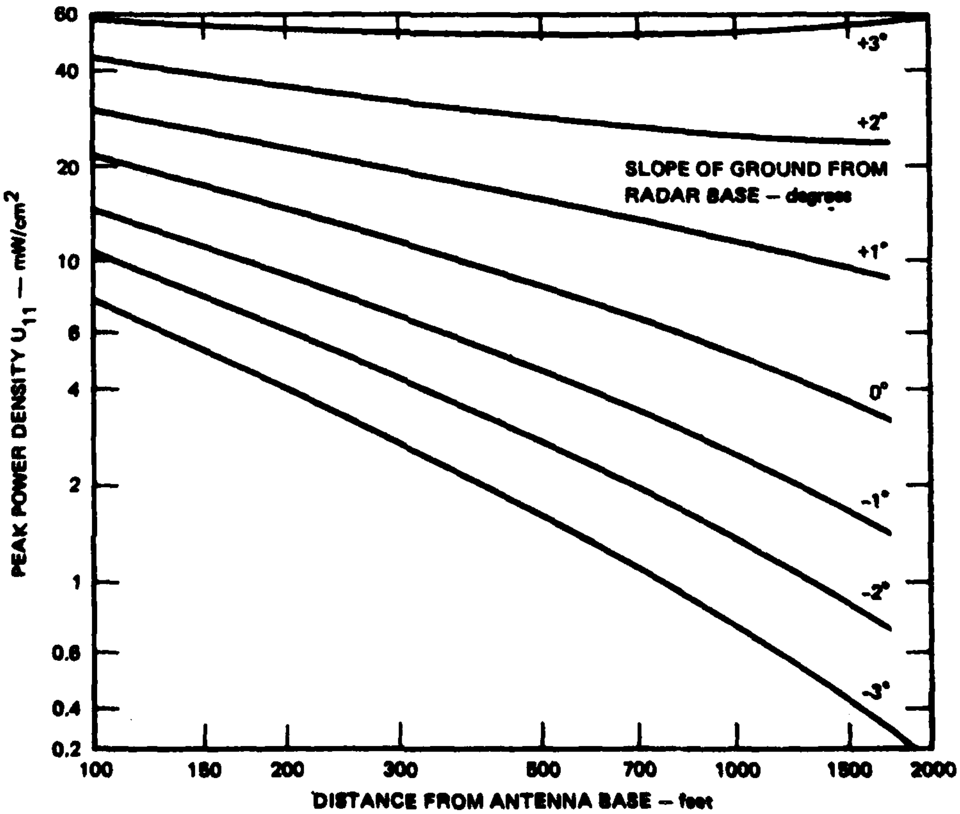

FIGURE B-7 PEAK POWER DENSITIES AT GROUND LEVEL IN NEAR FIELD

Table B-1

DISTANCES AND DEPRESSION ANGLES

S	r = 145 h	r = 145 R	r = 145 Y	r = 290 h	r = 290 R	r = 290 Y	r = 580 h	r = 580 R	r = 580 Y
+3	+6	123	17	+15	270	7	+30	562	2
+2	+4	122	18	+10	269	8	+20	562	3
+1	+2	121	19	+5	269	9	+10	561	4
0	0	120	20	0	268	10	0	561	5
-1	-2	119	21	-5	267	11	-10	560	6
-2	-4	118	22	-10	267	12	-20	560	7
-3	-6	117	23	-15	266	13	-30	559	8

S = elevation angle (deg)
R = horizontal distance (ft)
h = height (ft)
Y = depression angle (deg)
r = radial distance (ft)

the face of the array, the time- and space-averaged power density due to higher order sidelobes is 4.1 mW/cm^2.

The equation for U_g reaches this value at a distance R = 51 ft. There is no interest in such small distances; therefore, the expression $U_g = (1.1 \times 10^4 \cos Z)/R^2$ is used for all values of R. This expression is convenient to use because it is insensitive to the elevation of the ground. In contrast with the case for the far field, U_g represents the total average power density, and the near-field column of the main beam does not make a significant contribution.

B.2.4 Electric Field Intensities

Electromagnetic waves such as those generated by PAVE PAWS are characterized by electric and magnetic fields, both of which are perpendicular to the direction of propagation. Of these, the electric field is of principal interest. Under all conditions relevant to the present calculations, the electric field strength (or intensity) E is related to the local power density *U* by the equation

$$E = (3{,}770\ U)^{1/2} \tag{15}$$

where E is measured in volts per meter (V/m) and U is given in milliwatts/cm^2. The relationship is used only for peak values of E and U.

B.3 Beam Overlap

As shown in Figure B-8, a considerable area within ± 30 deg either side of 130 deg (the azimuth that corresponds to the system boresight, i.e., the common scan limit of both faces) is subject to radiation from both faces of the PAVE PAWS radar. This applies to both near-field and far-field regions. In the beam overlap region the peak power can never exceed that for a single face because the two beams are never sent in the same direction at the same time.

Figure B-4 shows that, for elevation angles above -2 deg, most of the time-averaged power is due to sidelobes of third or lower order. These sidelobes extend almost 5 deg from the main beam axis. Therefore, ground-level average power density may increase by a factor as large as 2 for angles within 5 deg of the system boresight.

B.4 Effect of Subarray Testing*

As stated in Section A.2.5, each of the 168 subarrays is tested once each 30 seconds with a 50-microsecond pulse. The power per subarray is 1,750/168 = 10.0 kW. The time-averaging coefficient for all subarrays is $168 \times 50 \times 10^{-6}/30 = 2.8 \times 10^{-4}$. The product of these two numbers is the total time-averaged power--2.8 W. This value is compared with $1,750 \times 0.15 \times 0.12 = 31.5$ kW, which is the time-averaged power distributed in higher order sidelobes from the total radar face. The ratio of these numbers is about 11,000. Therefore, the power devoted to transmitter diagnostics has no significant effect on the total RFR field.

B.5 Effect of Foliage and Scattering

B.5.1 Foliage

Microwave energy is absorbed and scattered by trees and underbrush. The effects of foliage on microwave propagation have been studied extensively (Trevor, 1940; Head, 1960; Doeppner et al., 1972; Tamir, 1977; Nelson, 1980). Waves that are forced to propagate directly through a forest are attenuated in an exponential manner. For woods typical of Robins AFB, the rate is about 0.05 dB/ft at PAVE PAWS frequencies; that is, the signal loses half its power (3 dB) in traveling a distance of about 60 ft. It is reduced to 1/10th its original strength in 200 ft and 1/100th its original strength in 400 ft.

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*As noted in Appendix A, details of the subarray testing remain to be determined. The amount of time devoted to subarray testing is so small that these changes cannot significantly affect the levels of total RFR.

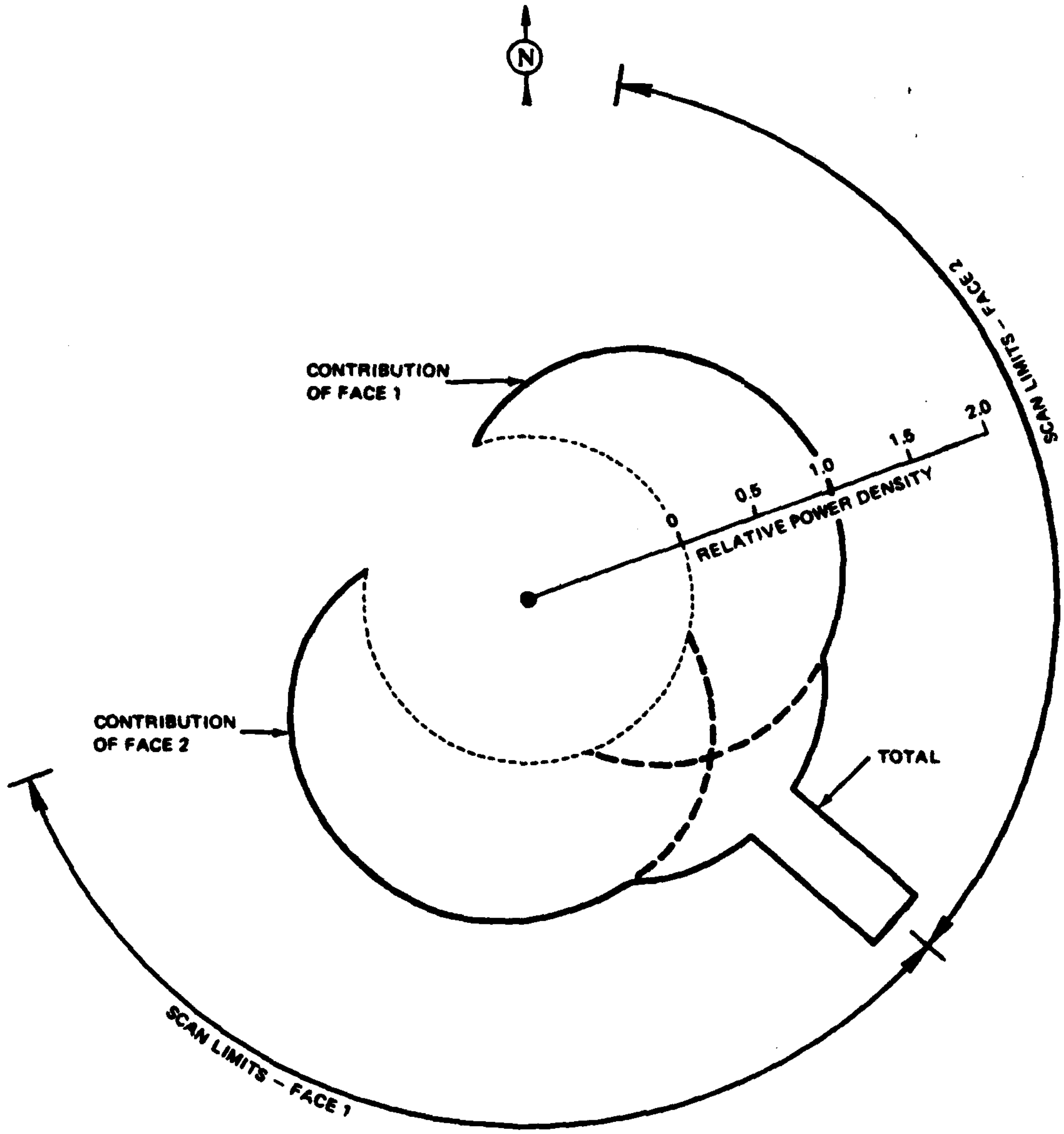


FIGURE B-8 POLAR PLOT OF RELATIVE TIME-AVERAGED POWER DENSITY VARIATION WITH AZIMUTH ANGLE, WITH SAME DUTY CYCLE APPLIED TO BOTH FACES

Over extended distances, waves find easier paths that curve around or skim over the tops of the trees. Such paths usually reduce the power to a value no larger than 1/100th of that which would exist over a direct free-space path. Waves that graze the treetops over a long distance behave somewhat like those that are guided over the surface of an imperfectly conducting earth, and the power density variation with distance includes a term of the form $1/R^4$.

In situations where vegetation provides shielding between the radar face and the location of interest, the RFR levels (both peak and average power densities) are likely to be reduced by a factor ranging from 10 to 100. This factor is not included in the numerical calculations that follow, the purpose being to provide extremely conservative (i.e., overstated) estimates of RFR.

B.5.2 Diffraction and Scattering

The faces of PAVE PAWS are directed away from most locations on Robins AFB, from which only the back of the radar is visible. Under these circumstances it might be thought that all the microwave power would be directed outward and that none would reach installations on the base. This ideal is closely approached, but a small residue of power propagates toward on-base locations by diffraction around the edges of the PAVE PAWS building and by scattering from trees, fences, and other objects that are in front of the two faces.

It is impractical to make precise calculations of the RFR that results from such effects, which are largely associated with the higher order sidelobes. A conservative upper bound is obtained by the principles of diffraction theory (Howell, 1976), which indicate that neither the peak nor the average power density within sector C will exceed 1/10 of that found at an equal distance in front of the radar. Referring to equation 10, the average power directly in front of the radar is $1.1 \times 10^4/R^2$. Therefore, the expression for average power in sector C is

$$U_9 = 1.1 \times 10^3/R^2 \quad . \tag{16}$$

By the same procedure from $U_2 = 0.001\ U_1$, the peak power density in sector C is

$$U_{10} = 3.1 \times 10^5/R^2 \quad . \tag{17}$$

Both U_9 and U_{10} are valid for all distances, and both are independent of and used in combination with any shielding associated with foliage between the radar building and the location of interest.

B.6 Enhanced Tracking or Reduced Power

The RFR in the vicinity of SEPP may be modified by either or both of two possible changes in operating conditions. These possibilities are discussed in the two following subsections.

B.6.1 Enhanced Tracking

Under possible but very unusual circumstances, the entire tracking function of PAVE PAWS may be assigned to one face. Under these conditions the duty cycle of that face is 25%; to avoid overtaxing the cooling system, the duty cycle of the other face must be reduced to 11%, and the total duty cycle of the radar is not increased above 36%. Ground-level RFR at all locations will actually decrease because the duty cycle of the surveillance fence of both faces will be reduced.

The condition of enchanced tracking has a relatively minor effect on the RFR and will occur rarely; therefore, it is given no further consideration.

B.6.2 Reduced Power

A remote possibility exists that the SEPP radar will be built and operated as a basic system in which only one-third of the dipole elements on each face are provided with amplifiers (and receivers). Thus, the levels of RFR that would result from such operation must be considered. The peak power would be decreased from 1,750 to 580 kW, and the gain of the array would also decrease from 20,500 to 6,850. Thus, the peak intensity of the main beam at any distance in the far field would be decreased by a factor of 9. The average power due to higher order sidelobes would decrease by a factor of 3. (Also, the diameter of the beam would increase by a factor of $(3)^{1/2}$ or approximately 1.7.)

Calculations based on these changed conditions have been made for various locations in the vicinity of SEPP. The result of these calculations is that no ground-level location would be subject to higher levels of RFR under these conditions than it would be for the full-power systems treated in previous calculations. This is true of both peak and average power and for all distances in the near and far fields. Thus, the values presented here represent maximum values, and lower values would exist should the lower powered (basic) version of the PAVE PAWS system be built and operated.

Another possibility is that two-thirds of the elements on one face and all elements on the other face will be used. Again, the RFR produced by this configuration will nowhere be higher than that of the full-power system.

B.7 Compilation of Formulas

The preceding sections of this appendix have developed a set of formulas and graphs for calculating electric field strengths and power densities at various locations in the vicinity of the PAVE PAWS radar. To facilitate subsequent calculations these relationships are collected in Table B-2, together with the conditions under which they apply. In sector B both peak and average power densities vary as the cosine of the angle away from the boresight axis. At Z = 84 deg the values calculated for sector B are the same as those for sector C.

Table B-2

SPATIAL REGIONS AND APPLICABLE FORMULAS FOR RFR[a,b,c,d]

	Sector A Z less than 64 deg	
Far field: R greater than 1,850 ft	$U_p = U_1K_1 = (3.1 \times 10^9 K_1)/R^2$	K_1 from Fig. B-2
	$U_a = U_4K_2 = (5.0 \times 10^6 K_2)/R^2$	K_2 from Fig. B-4
Near field: R less than 1,850 ft	$U_p = U_{11}$ (ground level)	U_{11} from Fig. B-7
	$U_p = U_0 = 910$ (main beam column)	
	$U_a = U_8\ (1.1 \times 10^4 \cos Z)/R^2$	

	Sector B Z is between 64 and 84 deg
All distances	$U_p = U_2 = (3.1 \times 10^6 \cos Z)/R^2$
	$U_a = U_8 = (1.1 \times 10^4 \cos Z)/R^2$

	Sector C Z is greater than 84 deg
All distances	$U_p = U_{10} = (3.1 \times 10^5)/R^2$
	$U_a = U_9 = (1.1 \times 10^3)/R^2$

---

[a] All power densities are in milliwatts/cm^2 and all distances are in feet from the center of the radar face.

[b] The angle Z is measured in degrees from the boresight azimuth of the face.

[c] The duty cycle of both faces is 15%, and the elevation of the surveillance fence is 3 deg.

[d] E_p = peak electric field intensity in V/m = $(3770\ U_p)^{1/2}$.

The formulas listed in Table B-2 are displayed in graphic form in Figures B-9 and B-10. Graphical interpolation has been used to produce a smooth blending across the various boundaries of distance, azimuth, and elevation angle.

In Figure B-9, the dashed-line segments near the top of the graph represent an envelope of maximum values of average power densities that could be encountered by airborne objects. The horizontal line segment corresponds to the region in front of either face at a maximum duty cycle of 25%. The sloping segment corresponds to the center of the beam overlap region (azimuth 130 deg, elevation +3 deg) at the center of the surveillance fence, with a combined duty cycle of 30%.

In Figure B-10 the dashed-line segments have a similar meaning. The horizontal segment represents the peak power density to be found directly in front of either face of the radar. The sloping segment represents the maximum peak power density to be found within the main beam, regardless of its direction.

B.8 Calculation of Ground-Level Fields at Specific Locations

Values of RFR field strength have been calculated for selected locations in the vicinity of the PAVE PAWS antenna. The configuration of the exclusion and security fences is expected to be the same whether Robins or Moody AFB is chosen. The location and shapes of these fences are important because they control the approach of the general public and the levels of RFR to which the public is exposed.

B.8.1 Power Densities at the Exclusion Fence

Power densities at the four locations indicated in Figure B-11 (same as Figure 4-4) have been calculated and are listed in Table B-3. Values given in Table B-3 were taken from Figures B-9 and B-10 on the assumption that the ground near the radar is essentially level. The highest calculated average power density is 0.10 mW/cm^2 and occurs at the exclusion fence on the system boresight axis, where both faces contribute to ground-level RFR.

B.8.2 Calculation of Ground-Level Fields at Other Locations

Values of RFR field strength have been calculated for seven sites near Robins AFB and seven sites near Moody AFB. The calculated values are intended to represent realistic estimates (i.e., the field strength at any given location produced by operation of the PAVE PAWS system may be either larger or smaller by a factor of 2 than the calculated values). The conditions assumed for calculating field strength at any location are: (1) during 15% of the time each face of the radar creates a surveillance fence with a beam elevation of 3 deg; and (2) the far-field radiation pattern used in the analysis for the main beam elevation angle of +3 deg is the same as Figure B-2, i.e, the pattern in the vertical plane computed for the main beam directed along the antenna boresight.

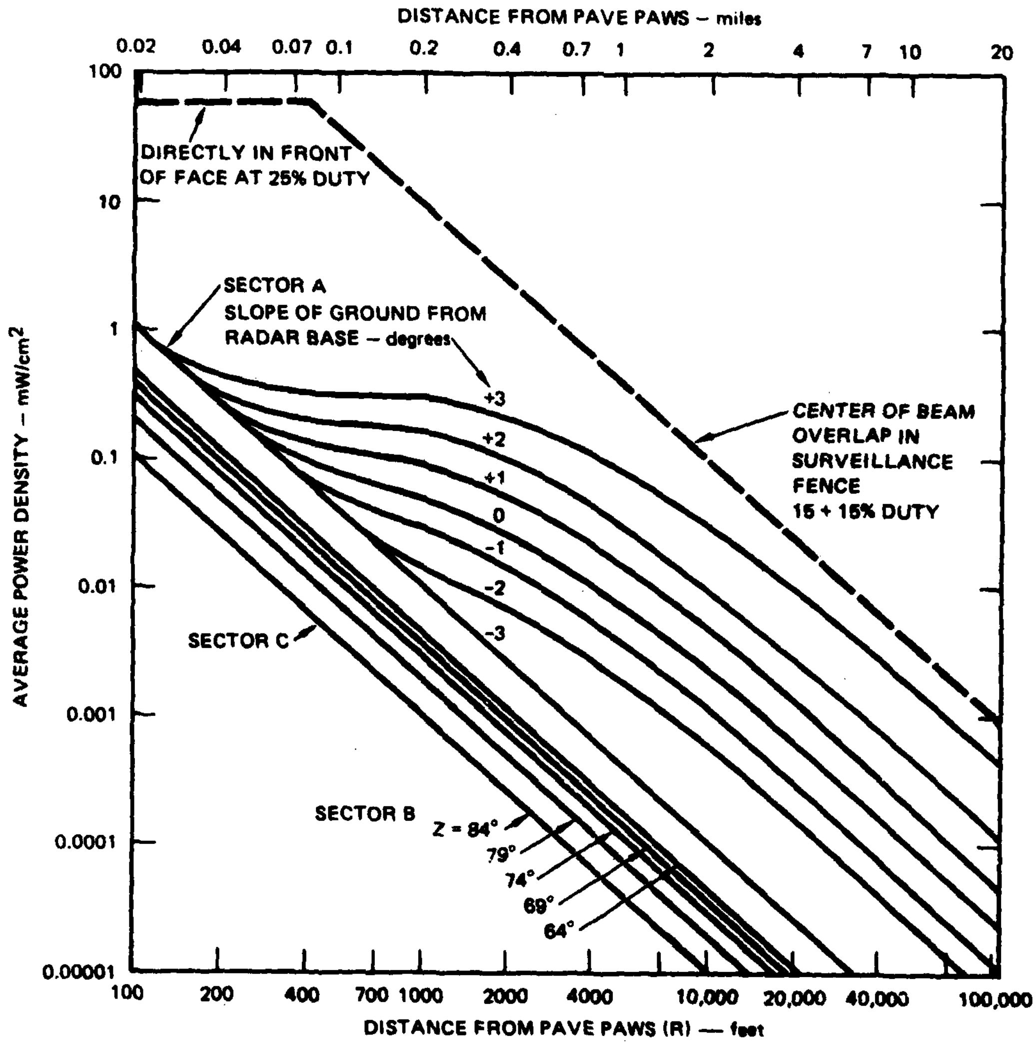


FIGURE B-9 AVERAGE POWER DENSITIES AT GROUND LEVEL NEAR SEPP

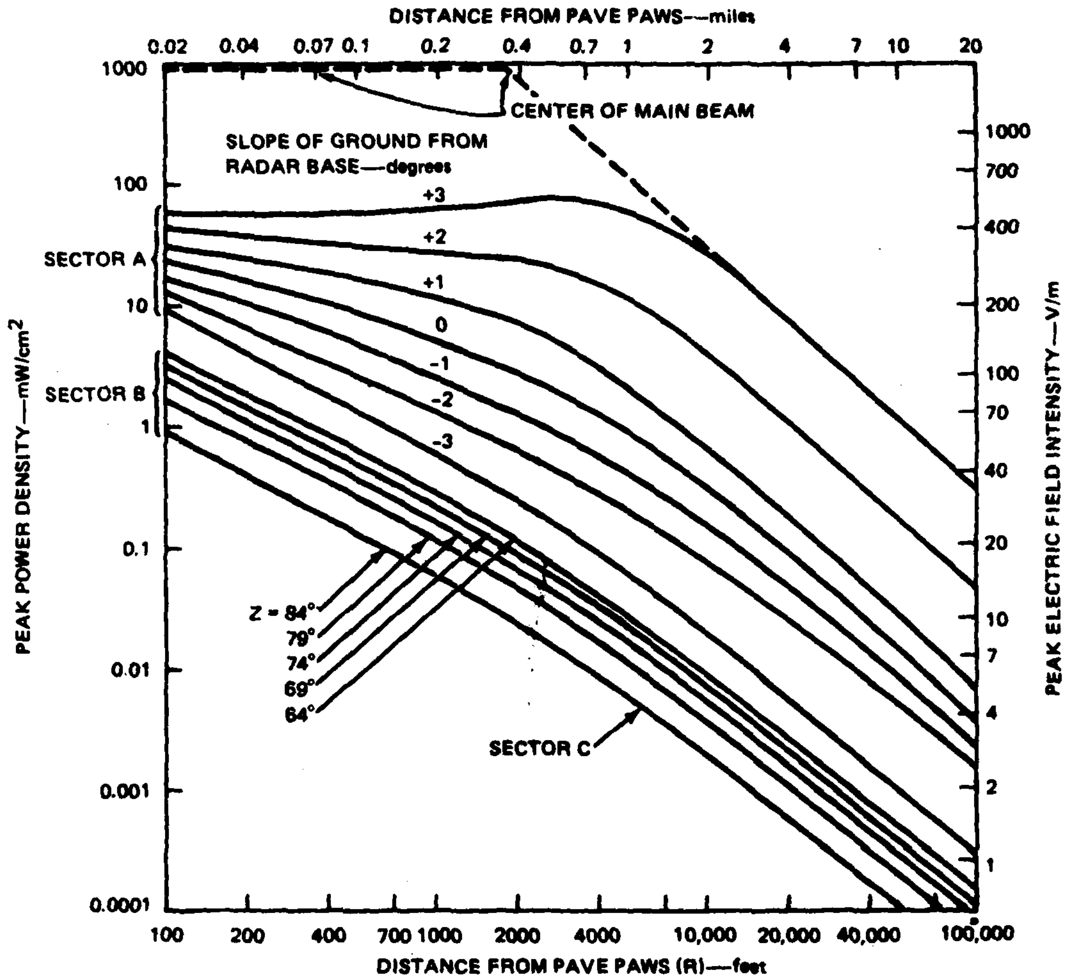


FIGURE B-10 PEAK POWER DENSITIES AND ELECTRIC FIELD INTENSITIES AT GROUND LEVEL NEAR SEPP

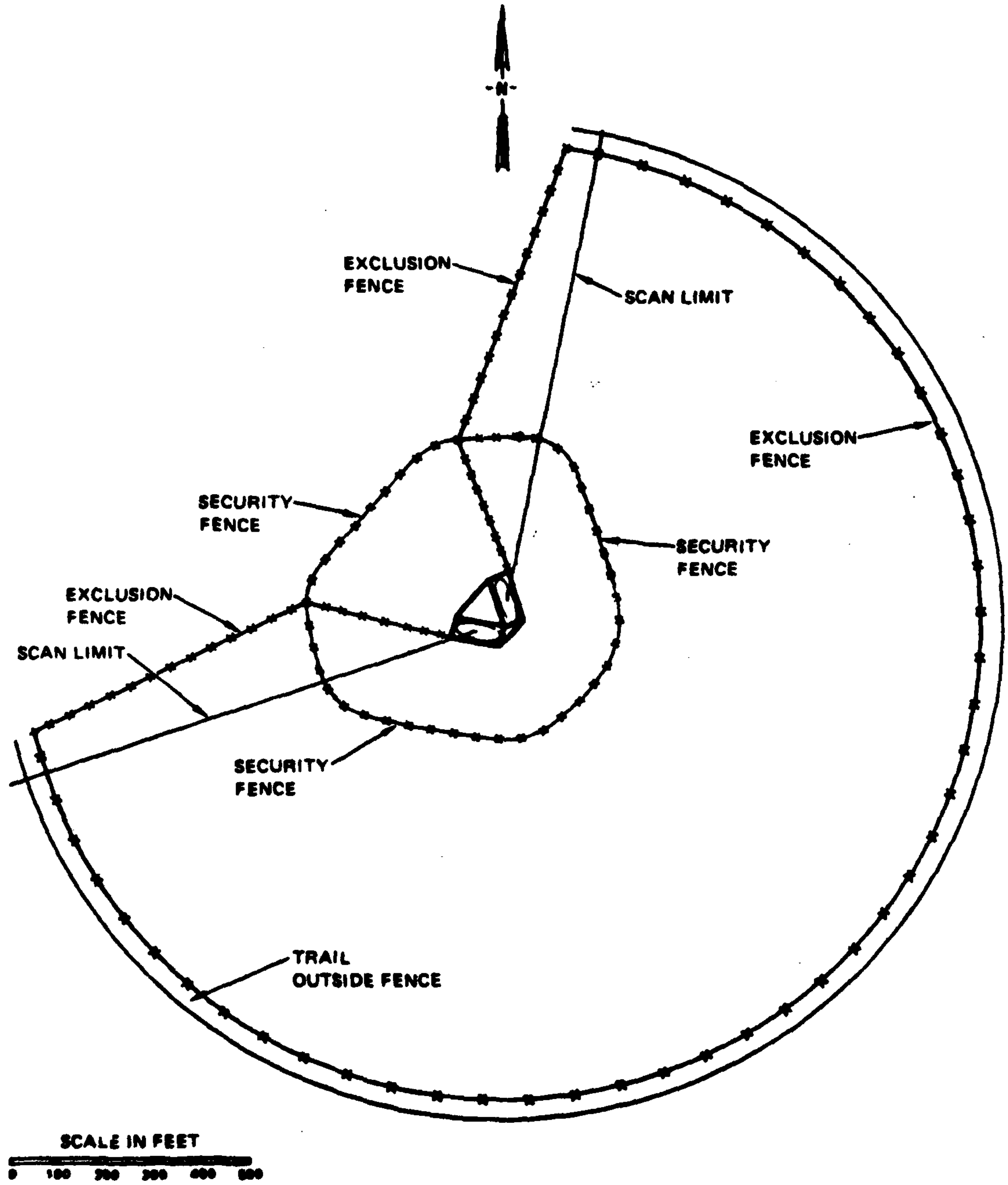


FIGURE B-11 TYPICAL SITE PLAN FOR SEPP

Table B-3

CALCULATED VALUES OF GROUND LEVEL RFR AT THE EXCLUSION FENCE[a]

Site No.	Relative Azimuth Z (deg)	Range R (ft)	Average Power Density U_a (mW/cm^2)	Peak Power Density U_p (mW/cm^2)	Peak Electric Field Intensity E_p (V/m)
1	90	300	0.012	0.27	32
2	74	500	0.012	0.40	39
3[b]	64	1,000	0.014	0.30	34
4[c]	60	1,000	0.10	5.0	137

[a] The area enclosed by the exclusion fence is assumed to be essentially level.

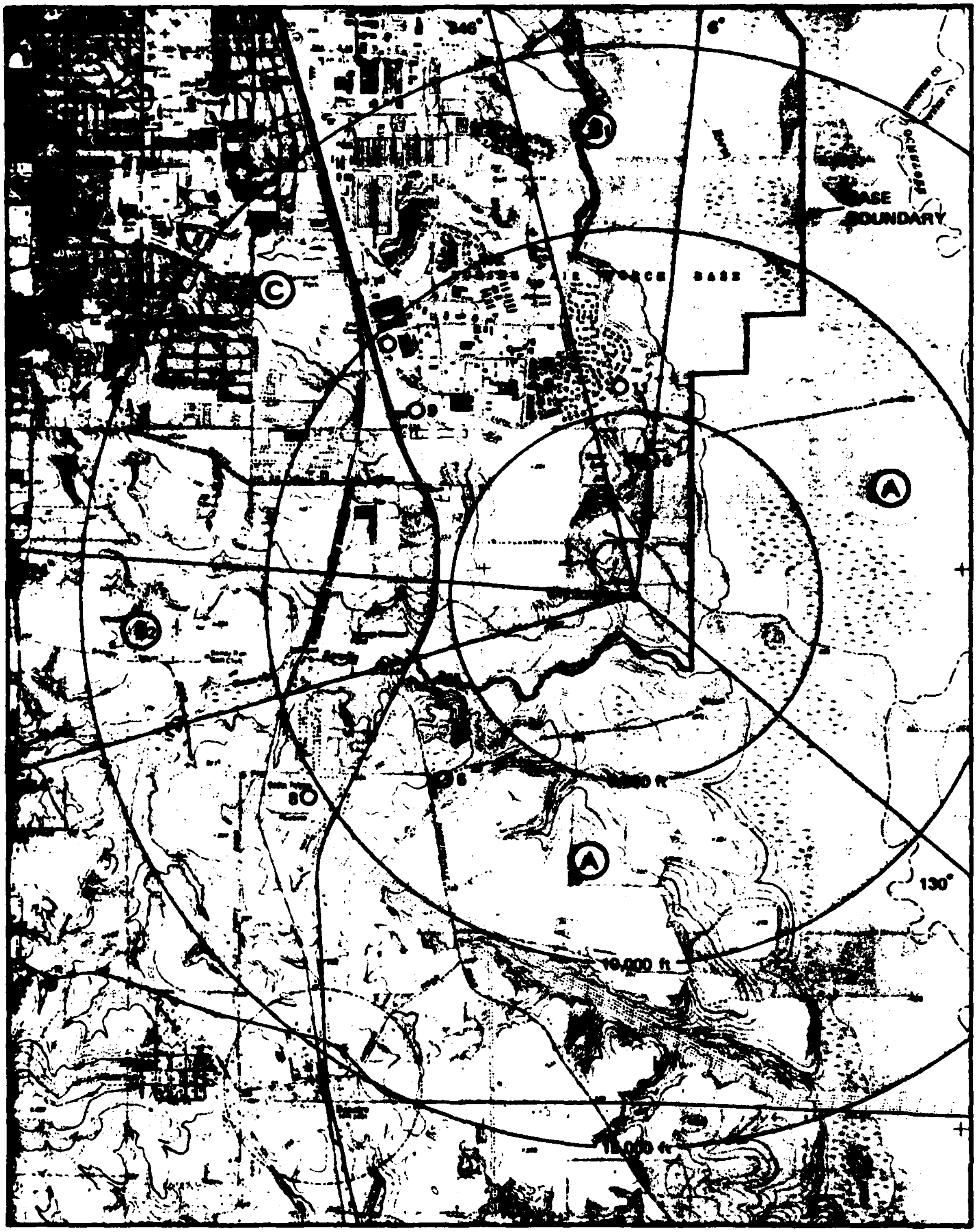
[b] The average power density at site 3 is calculated by taking an angle $(3^2 + 4^2)^{1/2} = 5$ deg from the beam axis.

[c] The average power density at site 4 has been doubled to account for beam overlap.

To facilitate calculations of on-axis main beam field strength at a specific distance from the antenna, we define r as a distance along the main beam axis. For near-surface locations, the points selected for analysis are described by the horizontal distance R between the antenna and the selected location. For the 3-deg elevation angle, $R = \cos 3$ deg $= 0.999r$. Therefore, except for locations very close to the radar, the horizontal distance R can be used in place of axial distance r with negligible error.

The beam diameter in the near field, considered to be the diameter of the antenna cross section projected in the direction of the beam axis, is determined by the antenna diameter and the angle between the antenna axis and the beam axis. This angle is 17 deg for the case of the 3-deg elevation angle and the 20-deg face inclination angle. The projected beam diameter, $D \cos 17$ deg $= 0.956D$, can be approximated by D with negligible error.

The seven sites near Robins AFB were chosen as representative of locations that might receive substantial RFR or would be of particular interest to local inhabitants. The positions of these selected sites in relation to the proposed SEPP site are shown in Figure B-12. Site 5 on the south shore of Luna Lake was chosen as the closest spot that is both within the scan limits and likely to be visited by many people. Site 6 is believed to be the nearest residence within the scan limits. Site 7



SCALE

0 0.5 1.0 1.5
Miles

FIGURE B-12 ROBINS AIR FORCE BASE — SITES SELECTED FOR ANALYSIS

represents the downtown area of the city of Warner Robins. Site 8, a tall radio tower, was chosen because of expressed concern. Concern was also expressed about interference with electronic activities at sites 9 and 10. Site 11 represents base housing.

Figures B-9 and B-10 were used to calculate ground-level field strengths at these seven locations. The calculations and resulting values of power densities and electric field strengths are presented in Table B-4. In no case does the far-field main beam strike the chosen site. The radio tower is struck by a portion of the first sidelobe. Sites 5 and 6 are subject to the second sidelobe. All others are subject only to higher order sidelobes.

The seven sites in the vicinity of Moody AFB were also chosen as representative of locations that are of community interest or likely to be subject to substantial values of RFR. They are indicated in Figure B-13. Sites near the exclusion and security fences were not considered because the RFR conditions are the same as at Robins AFB.

Site 15, a building near Highway US 221, is at the center of the beam overlap zone and relatively close to the radar; thus, the average power density is doubled at this location. Site 16 is a church near the intersection of US 221 and Academy Road. Site 17 represents the town of Bemiss, just outside the western scan limit. Site 18 is the school in the town of Naylor, Georgia, the closest population center within the scan limits. Site 19 is another church within sector A. Site 20 is Delmar Station on the Seaboard Coast Line Railroad. Site 21 is the tower at Moody AFB, assumed to be 50 ft high; the RFR value is relatively low because this site is well outside the scan limits of the system. No attenuation due to trees has been factored in; if trees are present, they will substantially reduce the RFR values.

The results of the calculations of ground-level field strengths are given in Table B-5.

B.9 Summary

B.9.1 Robins AFB

The largest values of ground level RFR occur at site 4, outside the exclusion fence at the center of the beam overlap zone (i.e., the system boresight). Here the time-averaged power density is 0.10 mW/cm^2. This value assumes that the area between the security fence and the exclusion fence is kept clear of trees and tall brush. More likely, the trees and underbrush in this area will be left undisturbed--except for topping as required to clear the main beam column. In this case the time-averaged power density here will not exceed 0.010 mW/cm^2. The values at sites 1, 2, and 3 will also decrease if trees are present.

Table B-4

CALCULATED VALUES OF GROUND LEVEL RFR AT SELECTED LOCATIONS NEAR ROBINS AFB

	Sector	Site	Elevation	R	Elevation Angle	Az	Z	U_a	U_p	E_p
Luna Lake south shore	A_1	5	285	3,700	+0.15	10	60	0.014	1.8	82
Residence SW of radar	A_1	6	360	7,000	+0.70	230	40	0.0075	1.1	64
City hall in Warner Robins	C	7	350	18,000	+0.24	320	87	0.000 003	0.000 75	1.7
Radio tower	A_1	8	450	9,800	+1.02	238	48	0.0048	0.80	55
Radar range	C	9	320	8,000	+0.32	310	87	0.000 016	0.0030	3.4
Avionic repair	C	10	280	9,500	+0.03	320	87	0.000 012	0.0024	3.0
Base housing	B	11	290	6,000	+0.14	356	74	0.000 08	0.014	7.3

U_p = Peak power density (mW/cm^2)
U_a = Average power density (mW/cm^2)
E_p = Peak electric field intensity (V/m)
R = Range (ft)
Az = Absolute azimuth (deg)
Z = Relative azimuth (deg)

Radar base elevation = 275 ft
Radar face elevation = 330 ft
Boresight azimuths = 70 and 190 deg
Scan limit azimuths = 10 and 250 deg
Surveillance beam elevation angle = 3 deg
Surveillance duty cycle = 15%

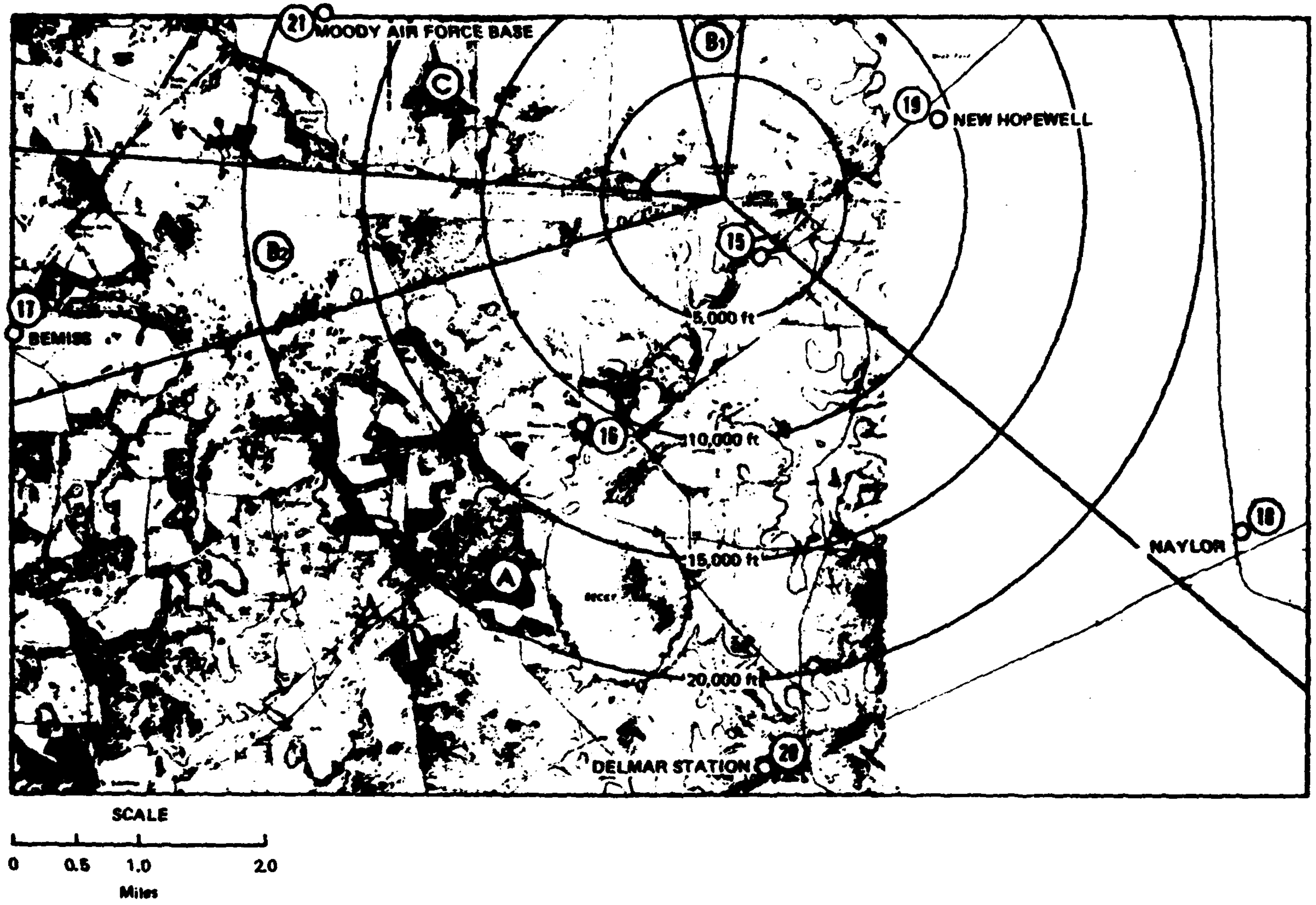


FIGURE B-13 MOODY AIR FORCE BASE — SITES SELECTED FOR ANALYSIS

Table B-5

CALCULATED VALUES OF GROUND LEVEL RFR AT SELECTED LOCATIONS NEAR MOODY AFB

	Sector	Site	Elevation	R	Elevation Angle	Az	Z	U_a	U_p	E_p
Building near US 221	A_1	15	200	2,800	+0.20	150	60	0.045	2.9	105
Pleasant Way church	A_1	16	210	11,300	+0.10	210	20	0.0022	0.33	35
Town of Bemiss	B	17	240	30,000	+0.12	259	69	0.000 0056	0.0011	2.0
Naylor School	A_1	18	190	25,500	0	124	54	0.000 38	0.060	15
New Hopewell Church	A_1	19	200	8,500	+0.07	72	2	0.0036	0.50	43
Delmar Station	A_1	20	195	23,500	+0.01	175	15	0.000 45	0.075	16.8
Towers on Moody AFB	C	21	280	18,300	+0.28	295	87	0.000 0030	0.000 75	1.7

U_p = peak power density (mw/cm^2)
U_a = average power density (mW/cm^2)
E_p = peak electric field intensity (V/m)
R = range (ft)
Az = azimuth (deg)

Radar base elevation = 190 ft
Radar face elevation = 245 ft
Boresight azimuths = 70 and 190 deg
Scan limit azimuths = 10 and 250 deg
Surveillance beam elevation angle = 3 deg
Surveillance duty cycle = 15%

Beyond the exclusion fence, time-averaged ground-level power densities continue to decrease in the manner indicated in Figures B-9 and B-10. These locations are shielded by trees, and the power densities are likely to be reduced by a factor of 10 from the tabulated values.

Luna Lake is centered on the scan limit and at a distance about half of the conventional far-field boundary (9,200 ft). Even when the effects of all trees are removed, the ground-level average power-density does not exceed 0.014 mW/cm^2. Substantially lower values of time-averaged power densities are indicated for all other sites listed in Table B-4.

B.9.2 Moody AFB

Here, as at Robins AFB, the largest values of ground level RFR occur at the exclusion fence, where the time-averaged power density is as high as 0.10 mW/cm^2. This is the highest value of RFR to which an individual outside the fences could be exposed. Of sites that are frequented by the general public, the building near US 221 (site 15) is subject to the largest values of RFR. Here the time-averaged power density is 0.045 mW/cm^2. This value will probably be reduced by a factor of 10 through attenuation caused by intervening foliage.

B.10 Validation

The validity of the methods used to derive the formulas compiled in Table B-2 has been confirmed by deriving similar formulas applicable to parameters of the PAVE PAWS system operating at Beale AFB, California, and then comparing the calculations based on those formulas with measurements made on 11 and 12 September 1979 at 18 selected sites nearby. The chosen sites are identified in Table B-6 and Figures B-14 and B-15. Calculated and measured values of RFR are compared in Table B-7. Some of the calculated values in Table B-7 differ from those appearing in Table B-2, p. B-5, of the Environmental Impact Statement, "Operation of the Pave Paws Radar System at Beale Air Force Base, California, March 1980." These differences are due to newer, more refined calculation methods.

The stated uncertainty of the average power measurements is ± 2 dB, corresponding to ratios between 0.63 and 1.6. The stated uncertainty of the electric field measurements is ± 4 dB, again corresponding to ratios between 0.63 and 1.6. (The apparent contradiction of these statements results from the fact that power varies as the square of the electric field.)

The measured value of the maximum electric field exceeds the calculated value only at sites 11, 13, and 18; in no case is the discrepancy greater than the uncertainty of the measurements. The same statement applies to the pulse power density values because they were derived from the electric field measurements.

The measured value of average power density exceeds the calculated value only at sites 11, 13, 16, and 18. Again, no discrepancy exceeds the known uncertainty of the measurement system.

Table B-6

BEALE AFB SITE IDENTIFICATION[a]

Test Site	Location	Azimuth (deg)	Distance (ft)	Elevation (ft)
1	Hospital	157	7,400	275
2	Lone Tree School	157	12,600	300
3	Trailer park	248	8,700	150
4	Control tower	280	22,000	215
10	Travelodge, Marysville	273	69,000	60
11	Main base water tank	298	5,800	294
13	Hilltop NW of radar	333	6,100	460
14	Housing NW of radar	344	12,000	270
15	Exclusion fence	186	950	360
16	Access road	130	3,250	440
17	Guard tower	22	150	395
18	Gate house	116	330	370
19	Yuba College	267	53,500	70
20	Security fence	186	290	360
21	Wheatland High School	211	51,700	75
22	Browns Valley	311	51,700	400
23	Rte. 65 and S. Beale Rd.	226	47,500	75
24	Hilltop NE of radar	22	5,100	600

[a] The base elevation of the PAVE PAWS at Beale AFB is 370 ft.

B.10.1 Test Conditions

Throughout the 11-12 September 1979 measurements, the radar was operated in an enhanced surveillance mode with 18% duty cycle applied to each face to produce the maximum possible exposure at ground level. For each location visited by the measurement team, the surveillance fence elevation was initially set at 3 deg; it was subsequently increased to 6 and 10 deg at the request of the field measurements team. Communication between test site and radar was maintained by a mobile radio link. Radar operating parameters were recorded during each measurement.

Under normal operations the radar frequency is stepped automatically through 24 frequency channels about equally spaced through the band from 420 to 450 MHz. During the RFR field measurements, the radar was operated at a fixed frequency of 435 MHz.

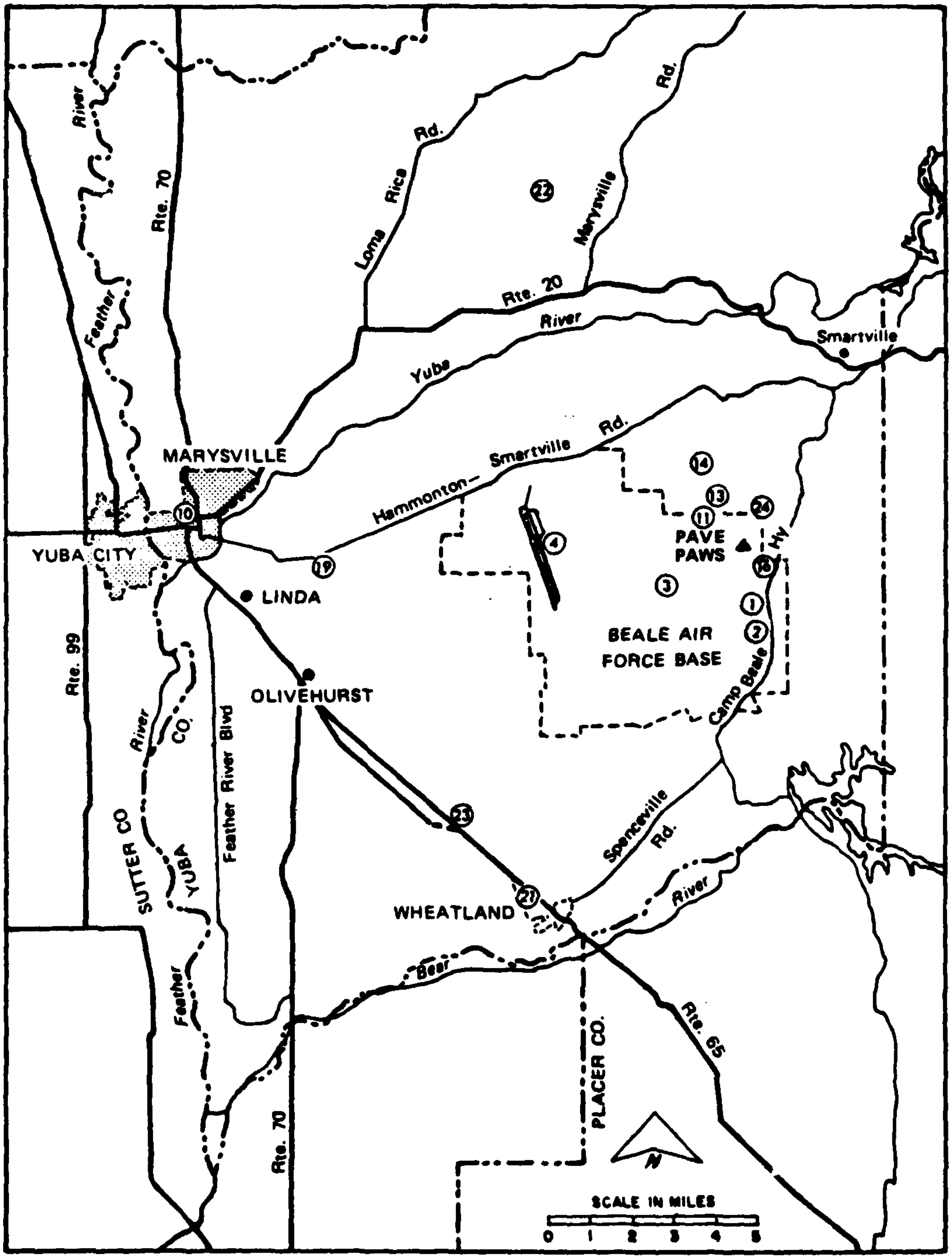


FIGURE B-14 BEALE AIR FORCE BASE–SITES SELECTED FOR MEASUREMENT

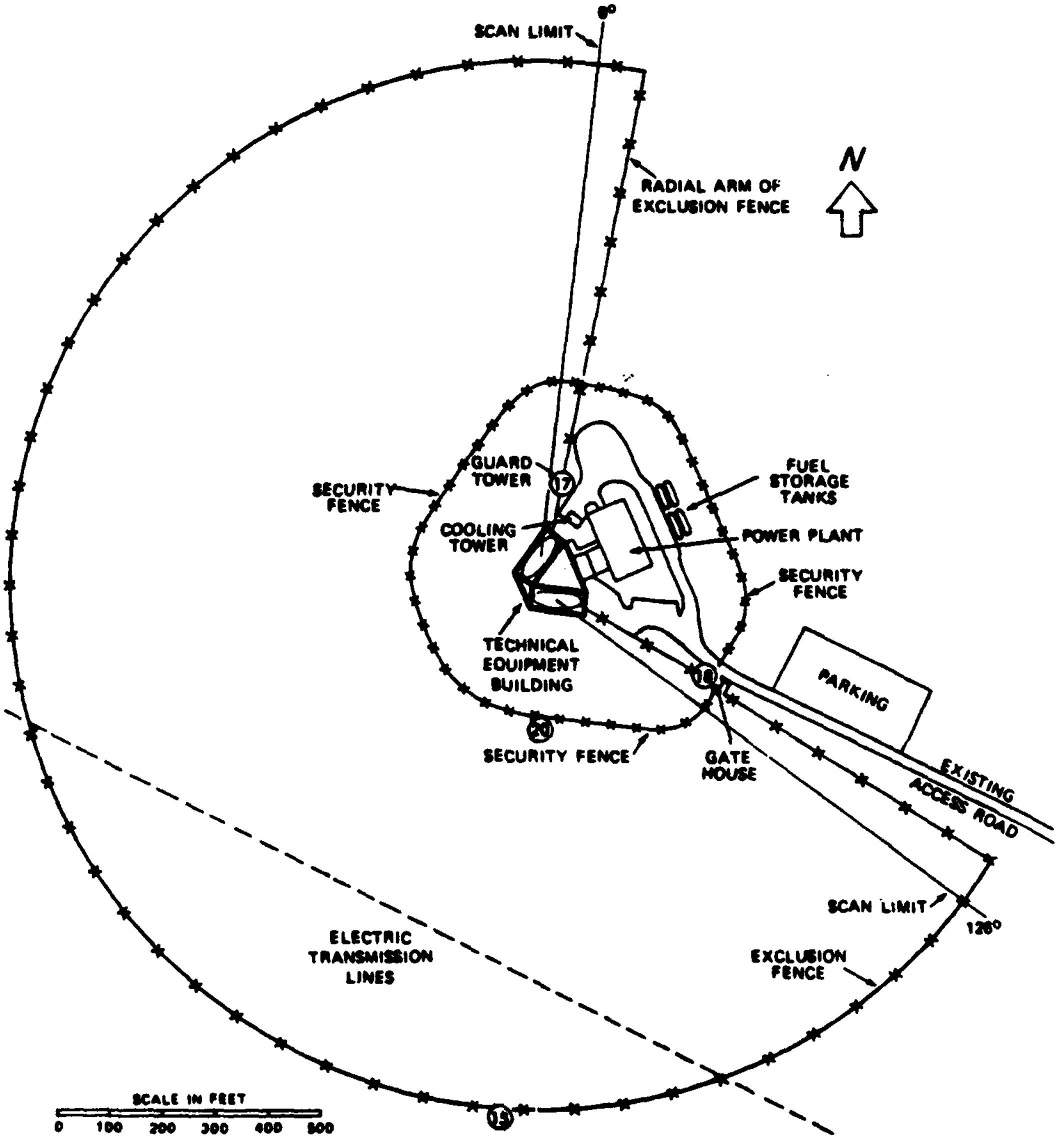


FIGURE B-15 PAVE PAWS SITE PLAN AT BEALE AIR FORCE BASE– SITES SELECTED FOR MEASUREMENT

Table B-7

COMPARISON OF MEASURED AND CALCULATED RFR
FOR BEALE AFB PAVE PAWS

Test Site[a]	Maximum Electric Field (V/m) Calculated[b]	Maximum Electric Field (V/m) Measured	Pulse Power Density (mW/cm²) Calculated[b]	Pulse Power Density (mW/cm²) Measured[c]	Average Power Density (mW/cm²) Calculated[b]	Average Power Density (mW/cm²) Measured
1	8.7	8.48	0.020	0.0191	0.000 33	0.000 132
2	8.5	5.50	0.019	0.008 03	0.000 16	0.000 047
3	3.9	2.11	0.0041	0.001 18	0.000 20	0.000 041
4	4.8	3.21	0.0061	0.002 73	0.000 052	0.000 014
10	1.6	0.13	0.00065	0.000 005	0.000 005	d
11	8.2	8.35	0.018	0.0185	0.000 51	0.000 80
13	17.7	20.0	0.083	0.106	0.000 69	0.000 96
14	8.0	2.77	0.017	0.002 04	0.000 15	0.000 013
15	35.8	17.9	0.34	0.0853	0.017	0.001 55
16	33.1	21.7	0.29	0.1253	0.0020	0.002 52
17	230	120	14.0	3.82	0.16	0.126
18	99	111	2.6	3.25	0.060	0.104
19	2.0	0.47	0.0011	0.000 06	0.000 007	d
20	118	106	3.7	3.00	0.18	0.111
21	2.1	0.37	0.0012	0.000 04	0.000 010	d
22	2.1	0.04	0.0012	d	0.000 010	d
23	2.3	0.55	0.0014	0.000 08	0.000 011	d
24	6.7	4.66	0.012	0.005 77	0.000 14	0.000 133

[a]These test site numbers correspond to those listed in Table B-6 and shown in Figures B-14 and B-15.

[b]Calculated by the methods of this appendix.

[c]The "measured" pulse power density is calculated from the measured maximum electric field using the equation $U = E^2/3770$.

[d]Below reportable levels (less than 0.000 001 mW/cm²).

B.10.2 Test Instrumentation

The test equipment, made up of unmodified standard commercial items, was configured to measure the RFR field generated by the PAVE PAWS radar. Calibration and certification of the test equipment were performed by the Keesler AFB Precision Measurement Equipment Laboratory, and all standards are traceable to the National Bureau of Standards. The 1839th Electronics Installation Group Laboratory did extensive testing and system calibration to verify the ability of the test instrumentation to measure accurately the complex RFR from the PAVE PAWS radar. Laboratory tests performed on the electric field intensity measurement system (field intensity meter, analog-to-digital (A/D) converter, and computer) showed an accuracy of $\pm$2.7 dB (multiplied or divided by 1.36) in measuring the voltage of pulsed signals with the characteristics of the PAVE PAWS radar. Laboratory tests performed on the average power measurement system (power sensor, power meter, A/D converter, and computer) showed an accuracy of $\pm$0.7 dB (multiplied or divided by 1.17) in the measurement of the power of pulsed signals produced by two signal generators with different pulse widths, pulse repetition frequencies, and power levels. On-site tests with the instrumentation in the van showed an uncertainty of $\pm$0.3 dB (multiplied or divided by 1.03 in voltage or 1.07 in power) in the RF cable, attenuators, and power divider. The gain of the test antenna was known to an accuracy of $\pm$1.0 dB (multiplied or divided by 1.12 in voltage or 1.26 in power). Combining these uncertainties yields an overall system accuracy for electric field measurments of $\pm$4.0 dB (multiplied or divided by a factor of 1.6), and an accuracy of $\pm$2.0 dB (multiplied or divided by a factor of 1.6) for average power density measurements. Because the pulse power density measurement is derived from the electric field strength measurement, it has an overall system accuracy of $\pm$4.0 dB (multiplied or divided by a factor of 2.5). (The apparent contradiction in these statements results from the fact that power varies as the square of the electric field.)

The instrumentation shown in Figure B-16 was installed in a screened enclosure in the mobile van used for all measurements in the survey. The screened enclosure prevented possible RFR interference with the equipment resulting from instrument penetration by RFR signals or noise.

B.10.3 Test Procedure

At each designated location for the far field measurements, the dipole test antenna was placed on a tripod and elevated about 2 m above the ground. The antenna and tripod were then moved horizontally until the received signal was maximized on the field intensity meter (tuned to the radar operating frequency of 435 MHz). This usually occurred within a horizontal distance of 1.4 m (2 wavelengths). This procedure established "worst case" conditions due to the addition of reflected signals to the incident signal. The test antenna was then oriented along three orthogonal axes, and the radiated signal for each antenna orientation was measured.

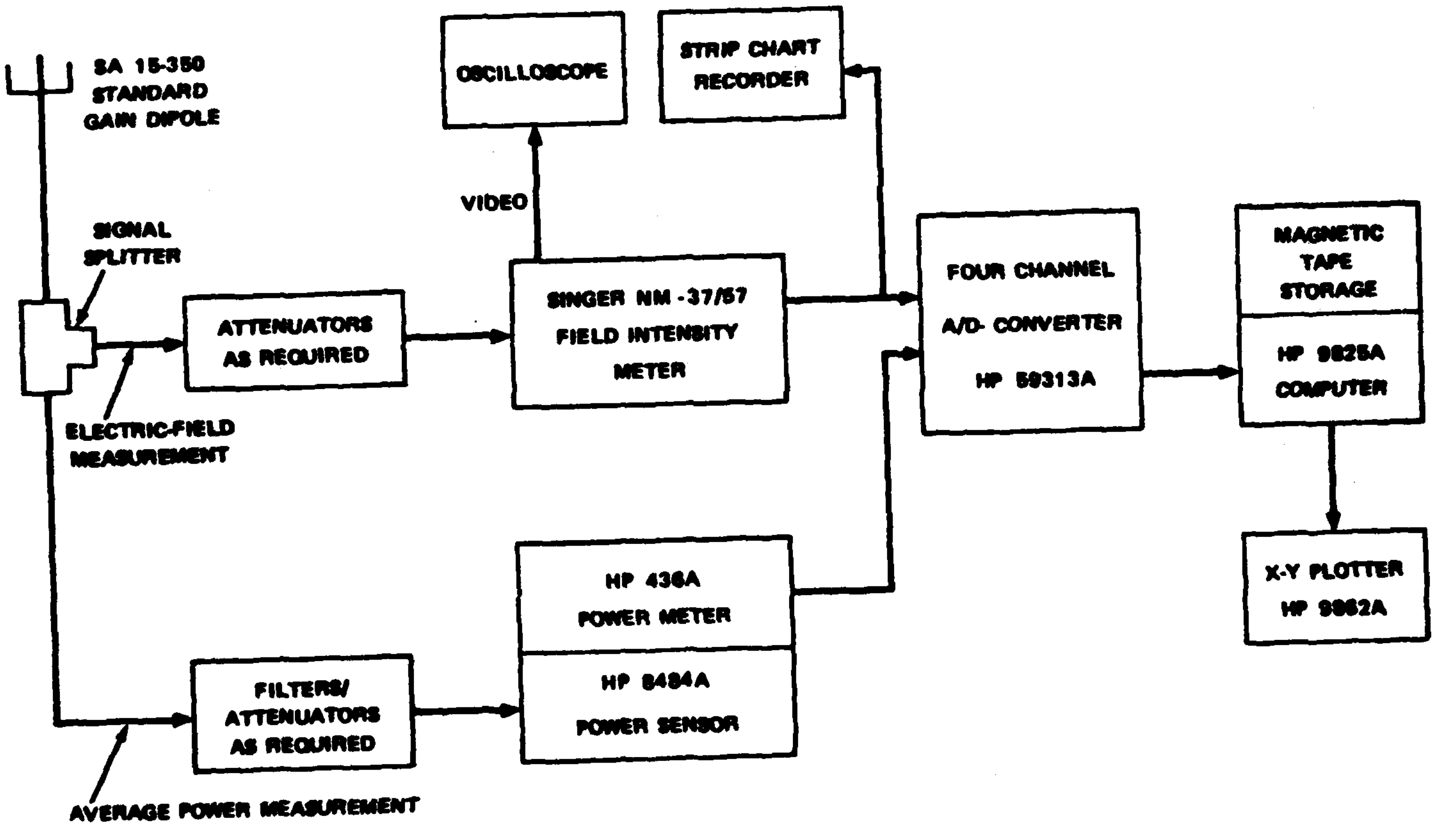


FIGURE B-16 BEALE AFB PAVE PAWS TEST INSTRUMENTATION

The electric field measurement needed to determine the value of the pulse power density was made with a Singer NM-37/57 field intensity meter (FIM); the data were processed by a desk-top computer (Hewlett-Packard 9825A) and recorded on magnetic tape. The A/D converter sampled the FIM output 50 times per second and provided the interface between the FIM and the computer. The average power density measurements were made with a Hewlett-Packard 436A power meter and 8484A power sensor. The A/D converter sampled the power meter output 167 times per second and provided the interface between the power meter and the computer.

The total average power density was calculated by summing the results of the individual measurements made with the test antenna in the three orthogonal orientations. This was done at each test location for each radar beam elevation measured. The total electric field was the vector sum of the individual orthogonal measurements (i.e., the square root of the sum of the squares of the three orthogonal measurements). Measuring with the dipole antenna in three orthogonal directions was essentially the same as measuring with an isotropic (nondirectional) antenna.

A total instrumentation verification was performed before and after the field measurements to validate the operation and accuracy of all test equipment and accessories.

B.11 List of Symbols

a	Identifies footnote
A	Area of array face
b	Identifies footnote
c	Identifies footnote
C	Velocity of light = 3×10^8 m/s
d	Identifies footnote
D	Diameter of array face
E	Electric field (volts/meter)
f	Frequency (hertz)
G	Antenna gain (ratio)
h	Elevation of point above radar base (ft)
J	Extent of near field (ft)
K	Power ratio from graph

L Wavelength = C/f (m)

m Meters; milli (as a prefix)

P Transmitter power (watts)

r Distance of point to radar face (ft)

R Distance of point to radar base (ft)

s Seconds

S Slope of ground above horizontal (deg)

U Power density (mW/cm^2)

V Volts

W Watts

X Angle from line perpendicular to face of array (deg)

Y Elevation angle of beam above horizontal (deg)

Z Azimuth from boresight direction (deg)

B.12 References

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Appendix C

ELECTROMAGNETIC INTERFERENCE AND HAZARDS TO SYSTEMS

C.1 Introduction

This appendix presents an analysis of the potential effects on other systems of the operation of a PAVE PAWS radar system at either Robins AFB or Moody AFB. The systems considered include those that use the electromagnetic spectrum, as well as others that are not designed to use the electromagnetic spectrum but that may nevertheless be susceptible to the energy radiated by the radar. Systems in the first group include telecommunication systems and other radars, all of which are designed to sense electromagnetic energy. Systems in the second group include cardiac pacemakers and electroexplosive devices (EEDs), which may inadvertently be subjected to the radar energy.

Appendix A describes the frequency and time behavior of the radar. Information on the characteristics of the emission is basic to an analysis of the effects of any emitter of electromagnetic fields. PAVE PAWS is a complicated system operating under computer control according to preprogrammed operating algorithms. Its beams do not sweep; rather, they probe from one azimuth to another in a seemingly pseudorandom manner. PAVE PAWS has a repertoire of pulse widths, and it continually switches frequency. The operation is not predictable from moment to moment, because the computer may alter the routine surveillance operation to provide tracking data on some of the objects the radar detects and also because some of the available frequencies may not be used if they are experiencing interference. At all times, the radar is responding to outside influences according to well-defined rules programmed into the computer. Section C.2 of this appendix builds on the material of Appendices A and B to discuss the illumination of airborne and ground-based objects, considering the radar's behavior both in time and in frequency.

Section C.3 analyzes the incidental electromagnetic effects of PAVE PAWS. It is divided into two parts: Section C.3.1 discusses the effects on other telecommunication systems, and Section C.3.2 discusses three inadvertent receivers of energy. In both sections, the approach is to determine whether and how the subject system may be susceptible to the characteristics of the PAVE PAWS signal. We first consider the pulse widths, apparent pulse repetition frequency (PRF), and frequency-switching characteristics of PAVE PAWS, and then we attempt to determine the PAVE PAWS signal levels at which the subject system will experience some effect. Having determined those levels, we can estimate the distance from PAVE PAWS at which the effect will occur.

C.1.1 Background

To determine the likelihood that an emitter of electromagnetic fields will cause electromagnetic interference (EMI) to some other system, some knowledge is required of the operating characteristics of

both systems and of how the electromagnetic energy is propagated from one to the other. We often speak of the threshold of susceptibility for a system subject to interference. The threshold is the lowest level of undesired signal that will cause some perceptible effect on the susceptible system (or activity). Susceptible systems include radar and communication systems and cardiac pacemakers; activities include the handling of volatile fuels and EEDs.

The threshold of susceptibility typically must be determined separately for each pair of interfering system and potentially interfered-with system. That is because the threshold of susceptibility depends not only on the power density of the undesired signal at the potentially susceptible system (and therefore on the distance between them), but also on the frequency of the undesired signal, its pulse length and PRF, and, when applicable, on the strength and frequency of the desired signal. (Examples: TV receivers tuned to channel 10 would show effects that would not occur if they were tuned to channel 12. A satellite communication system may be susceptible to interference from only a few of the 24 PAVE PAWS channels. A cardiac pacemaker will be insensitive to the difference in frequency between the PAVE PAWS channels but will react differently to different pulse rates. A certain radar altimeter is affected in the same way by all PAVE PAWS frequencies, but it becomes increasingly susceptible as the interfering pulse widths increase.) Potentially susceptible systems of the same class (such as land mobile receivers) will differ in actual susceptibility because of differences in their design.

Theory is useful in predicting likely modes of interference, and it can go far in helping to predict thresholds of susceptibility. Measurements, however, are often needed, either when theory is not sufficient or to confirm the theoretical results. Unfortunately, each new situation is usually unique in some way, and susceptibility thresholds applicable to that situation are generally not available. For example, inquiries to the persons responsible for research on EMI in the Electronics Industries Association and in a major U.S. manufacturer of TV receivers reveal that they have no data on the effects of radars such as PAVE PAWS on their products. Table C-1 (taken in part from Donaldson, 1978) shows the variables that should be considered in a test program to define the effect clearly. If each possible test configuration were used, 1.53×10^{10} (more than 15 billion) tests would be required, which is clearly unrealistic. (This example is for TV receivers, but the nature of the problem would be similar for some other potentially susceptible system.)

PAVE PAWS generates signals of a highly unusual type, and little information is available to define accurately the susceptibility thresholds of the various systems in its vicinity to its unique type of interfering signal. Some measurements were taken almost 10 years ago on the effects on some systems of a phased-array radar, in the same 420- to 450-MHz band, and we have used that information to the extent possible (Conklin, 1974). The PRF and pulse width (and possibly the frequency hopping) of that radar, however, were different from those of PAVE PAWS, so the results are not directly applicable.

Table C-1

POSSIBLE TEST VARIABLES FOR TELEVISION RECEIVER SUSCEPTIBILITY TESTS

Number in Sample	Variable
50	Television sets
82	Channels
24	Interference source frequencies
3	Desired-signal levels
3	Interference-signal levels
3	Pulse widths
3	Pulse repetition frequencies
2	Effects (audio and video)
4	Television orientations
5	Television antennas
2	Picture scenes
4	Test configurations
	Television and antenna
	Television alone
	Antenna alone
	Power line
2	Receiver types (color and monochrome)
3	Independent viewers

Because of a combination of circumstances, making definitive statements regarding distances from the radar beyond which a given system will not be affected is rarely possible. Available measured susceptibility levels are generally based on measurements of only a very few units, generally selected in the hope that they are representative or typical of their type. They could, however, be either more or less susceptible than the entire population of units of that type. The variation in the susceptibility levels of all the units of a type (taken as a group) may be quite large, but this is generally unknown. In addition, circuit designs change, and the susceptibilities of the systems change with them. The nature of radiowave propagation over irregular terrain is such that the level of the interfering signal will not be the same at all locations the same distance from the source. At a given location, the level varies with time, and so dealing with expected, or median, values is common. That is also true of the desired signals, when they are applicable.

In some situations, attempting to determine actual susceptibility is not necessary; standards for maximum fields have been established so that the devices or systems are said to be safe if that field is not exceeded. This is the case for EEDs and for fuel handling, and a draft standard exists for cardiac pacemakers.

C.1.2 Scope

In the analyses in Section C.3, we have used combinations of theory and measured data as applicable to develop statements regarding the EMI effect of the PAVE PAWS electromagnetic fields.

C.2 The Received PAVE PAWS Signal

The Southeast PAVE PAWS radar (SEPP) differs considerably from the two PAVE PAWS radars on Beale AFB and Otis ANG Base in the timing of its pulses. Because SEPP is intended to detect targets at a greater range, it must "listen" for a longer period after transmitting a pulse. As of September 1982, no details of the timing of pulses had been established. Generally, though, we know that SEPP will devote almost all of its resources to maintaining the surveillance fence, and relatively few to tracking. Thus, it will illuminate the surveillance volume more often than other PAVE PAWS radars; completing a scan of its surveilliance volume will not take as long. The duty cycle will be lower.

Many of the numbers in Sections C.2.1 and C.2.2 can be only rough estimates based on our understanding of the operation of the two previous PAVE PAWS radars, which use a 54-ms resource, and the information that SEPP uses a 65-ms resource and spends minimal time tracking. All of these estimates are subject to change as part of the optimization of the system, and are so indicated. It is very unlikely that any of the estimates differ from the eventual design by a factor greater than 2, which does not strongly influence any of the EMI conclusions.

C.2.1 Illumination Durations of an Airborne Object

An aircraft or other object flying in the 240-deg sector searched by PAVE PAWS would be illuminated by the surveillance-mode main beam when it is in the upper shaded region indicated in Figure C-1. This raises the possibility that PAVE PAWS could affect airborne systems, a possibility discussed in Section C.3.1.5.

The object would not be illuminated often; if it were an aircraft, it would never be tracked. If SEPP were operated like the previous PAVE PAWS radars, there would be 60 surveillance beam positions per face, spaced approximately every 2 deg. In normal operation, the radar completes its long-range surveillance sequence in about 45 s,* illuminating a total of 642 beam positions at an estimated average rate of about 14 beam positions per second.* Although some beam positions are illuminated more often than others, on the average a beam position (and any object in it) would be illuminated by only 1/60 of the long-range surveillance pulses, or only about 0.24 times per second.* Thus, the main beam could illuminate an airborne object with the 5-ms or 8-ms long-range surveillance pulse only about once every 4 s.*

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*These numbers are subject to change during final system optimization.

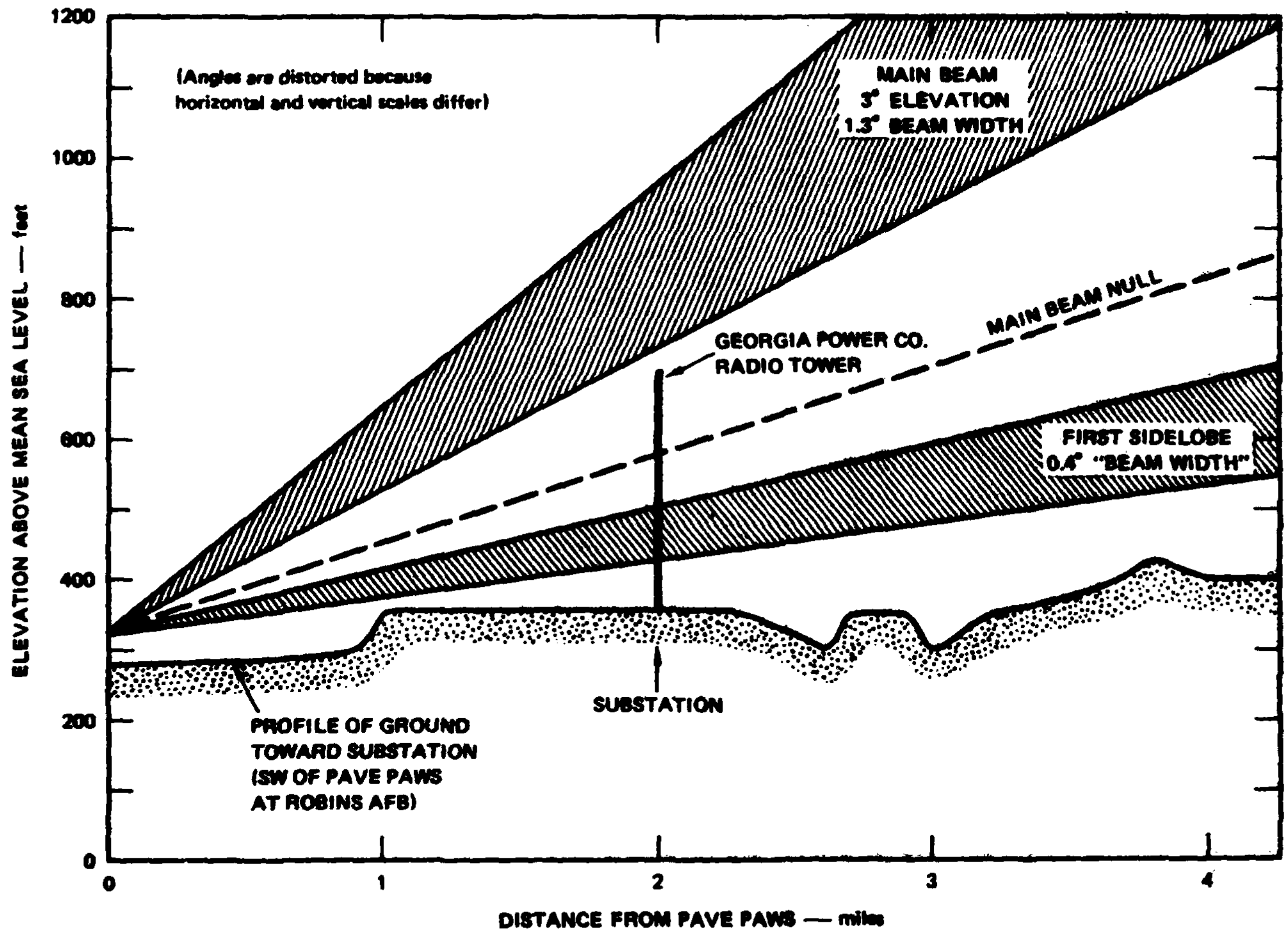

FIGURE C-1 VERTICAL PLANE CUT OF PAVE PAWS BEAM IN SURVEILLANCE MODE

A similar analysis of the short-range surveillance mode, based on the other two PAVE PAWS radars, shows that the radar illuminates 261 beam positions during its normal sequence of about 9 s,* for an average rate of about 28 beam positions per second.* Each of the 60 beam positions would be illuminated by a 300-microsecond short-range surveillance pulse at an average rate of about 0.47 times per second, or about once every 2 s.*

Because the radar switches the beam from one part of the sky to another with each succeeding pulse, the object--moving or stationary--will not be illuminated by consecutive pulses. While it is in the surveillance volume, we would expect the object to be illuminated by the main beam with a long-range surveillance pulse about 0.24 times per second and with a short-range surveillance pulse about 0.47 times per second. Thus, some sort of main-beam surveillance pulse hits, on the average, about 0.7 times per second,* or once every 1.4 s.* Track pulses would very rarely illuminate the object. Because the tracking volume is approximately 26 times greater than the surveillance volume, and because the main beam is very rarely directed there, an aircraft would be very unlikely to ever be illuminated with a track pulse.

An aircraft in position to be illuminated with the main beam would also be illuminated by energy from the first sidelobe (with a power density 0.025--16 dB less than--that of the main beam power density), by energy from the second sidelobe (with a power density 0.013--19 dB less than--that of the main beam), and by energy from the minor sidelobes (with a power density no greater than about 0.0001--30 dB less than--that of the main beam). First-sidelobe energy would illuminate the aircraft in the surveillance volume only when the surveillance-mode main beam is directly to either side of the aircraft. These first-sidelobe pulses would therefore hit the craft about twice as often as main-beam surveillance pulses, or about 1.4 times per second.* During each transmitter pulse for which the aircraft is illuminated by neither the main beam nor the first sidelobe, the aircraft would be illuminated by the higher order sidelobes. Even when the aircraft is not within the surveillance volume, it could be illuminated by the first sidelobe (as is indicated in Figure C-1) and by the higher order sidelobes.

C.2.2 Illumination Durations of a Ground-Based Object

The main beam never grazes the earth. First-sidelobe and second-sidelobe energy may strike the earth at various distances from the radar, depending on the terrain at a particular azimuth (see Section B.8 in Appendix B). Generally, objects will be illuminated only by the radar's second- and higher order sidelobes (that is, those beyond the second). The higher order sidelobes are located at angles greater than about 4 deg

*These numbers are subject to change during final system optimization.

from the main beam. Consequently, a nearby object is likely to be illuminated by one of the higher order sidelobes regardless of the direction of the main beam, and the object will be illuminated during each of the radar's pulses. Only objects at some elevation above the radar (which depends on the distance) will also be illuminated by the first sidelobe.

In contrast to most radars, PAVE PAWS does not have a specific PRF because it uses several pulse lengths and has various interpulse intervals. The number of pulses per second can be estimated, but that will not be a PRF in the usual sense. Each second, an average of about 14 long-range surveillance pulses and about 28 short-range surveillance pulses are emitted.* Thus, about 40 pulses of some kind will be emitted per second.* They will be of various widths and have various interpulse intervals.

Now consider the duration of an object's illumination by the higher order sidelobes, which should correspond with the radar's duty cycle. The duration of each of the approximately 14 long-range surveillance pulses emitted each second is either 5 ms or 8 ms.* The 8-ms pulses are used at azimuthal angles greater than 45 deg off the boresight. An average of about 28 300-microsecond short-range surveillance pulses are also emitted each second.* If we assume that half of the long-range surveillance pulses are 8 ms and half are 5 ms in duration, and if we add these durations and those of the short-range pulses, we find that an object is illuminated by surveillance pulses for about 99 ms/s, or about 10% of the time. Since the overall duty cycle of the radar is said to be 15%, consisting almost entirely of surveillance activity, the above estimate is somewhat low. However, it is reasonable, considering that SEPP resources have not yet been allocated, and is accurate enough for estimating EMI.

In addition to illumination by the higher order sidelobes, those objects illuminated by the first sidelobe would experience its greater pulse power density, but less frequently. There will be about 1.4 surveillance pulses per second (about 0.5 long-range surveillance pulses and about 0.9 short-range surveillance pulses per second).* For tracking, the main beam will generally be pointed higher than the 3-deg elevation angle; therefore, first-sidelobe tracking pulses at ground level are not likely. The time duration for first-sidelobe illumination, combining long-range and short-range surveillance pulses as in the preceding paragraph, is about 3.5 ms/s, or about 0.35% of the time.

C.2.3 Pulse Power Density

At distances greater than about 1,850 ft and in the main beam, the power density of a PAVE PAWS pulse is (from the far-field equations of Table B-2)

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*These numbers are subject to change during final system optimization.

$$P_r = 60.5 - 20 \log d \quad dBm/m^2$$

for d miles. (The dimension dBm/m^2 is defined as decibels relative to 1 milliwatt per square meter.) The pulse power density of the first sidelobe is 16 dB less than that of the main beam:

$$P_r = 44.5 - 20 \log d \quad dBm/m^2 \quad .$$

The pulse power density of the second sidelobe is 19 dB less than that of the main beam:

$$P_r = 41.5 - 20 \log d \quad dBm/m^2 \quad .$$

The maximum value for the higher order sidelobes is about 30 dB lower than that of the main beam, so illumination by that particular sidelobe has a pulse power density of

$$P_r = 30.5 - 20 \log d \quad dBm/m^2 \quad .$$

From Section B.5.2 (Appendix B), the pulse power density behind the radar, resulting from scattering and diffraction, is no greater than

$$P_r = 20.5 - 20 \log d \quad dBm/m^2 \quad .$$

The pulse power densities derived by these equations apply in line-of-sight situations throughout the surveillance and the tracking volumes and behind the radar. In other situations, the pulse power density will be much less. For areas that are shadowed by terrain, a conservative estimate would be that the pulse power density is at most one-tenth as great (at least 10 dB lower).

For areas that are shielded by the thick foliage of the forests surrounding the two potential SEPP locations, the peak power density values of the second-order and higher order sidelobes, as indicated above, are attenuated by at least an additional 10 dB.

C.3 PAVE PAWS Effects on Systems

C.3.1 Telecommunication Systems

C.3.1.1 Effects on Amateur Radio--A Secondary Service

Besides sharing the 420- to 450-MHz band with other radars, PAVE PAWS shares it with the Amateur Radio Service. Although the amateurs operate as the primary service in some bands, the Federal Communications Commission (FCC) considers the Amateur Radio Service to be a secondary service in this band; the band's primary service is radiolocation (i.e., radars). Secondary services do not enjoy the privileges of primary services. The following excerpt from Volume II, Section 2.105, of the FCC's Rules and Regulations (1972) defines the rights of each:

Note 1. Geneva Radio Regulation No. 138: Permitted and primary services have equal rights, except that, in the preparation of frequency plans, the primary services as compared with the permitted services, shall have prior choice of frequencies.

Note 2: Geneva Radio Regulation No. 139: Stations of a secondary service: (a) Shall not cause harmful interference to stations of primary or permitted services to which frequencies are already assigned or to which frequencies may be assigned at a later date; (b) cannot claim protection from harmful interference from stations of a primary or permitted service to which frequencies are already assigned or may be assigned at a later date; (c) can claim protection, however, from harmful interference from stations of the same or other secondary service(s) to which frequencies may be assigned at a later date.

Amateurs are normally authorized to use a transmitter output power of 1,000 W. To minimize interference with government operations (the primary users of the 420-450 MHz band), however, the FCC requires amateurs to use lower powers in certain restricted areas around selected military facilities. Responding to a request by the National Telecommunications and Information Administration, on 1 July 1982 the FCC issued Order FCC 82-302, which amended Part 2 (Table of Frequency Allocations) and Part 97 (Amateur Radio Service Rules) of the Rules and Regulations as they affect the areas surrounding four Air Force bases. Power restrictions of 50 W for amateurs in the 420-450 MHz band were established within a 100-mile radius of Elmendorf AFB, Alaska, and Grand Forks AFB, North Dakota. The 50-W power restriction in that band was extended from 50 to 100 miles surrounding PAVE PAWS at Otis ANG Base, Massachusetts, and was extended from 50 to 150 miles surrounding PAVE PAWS at Beale AFB, California.

C.3.1.1.1 Effects on Amateur Repeater Operation. The amateurs operate a number of FM repeaters (relays) in the band between 440 and 450 MHz to permit communication over greater distances than would otherwise be possible. To obtain coverage of large areas, the repeaters are generally placed on mountaintops, tall buildings, or towers. A repeater typically consists of a receiver and a transmitter; the receiver output is fed directly into the transmitter, operating at a frequency just 5 MHz away. In some parts of the country, the repeater's receiving frequency is 5 MHz higher than its transmitting frequency; in other parts of the country, the reverse is true.

The 1982-1983 Repeater Directory of the American Radio Relay League (ARRL) lists no repeaters in the PAVE PAWS band in Georgia (Clary, 1982). However, because repeater owners only optionally list their equipment in the directory, there may be unlisted repeaters in this band in Georgia. Although the 1978-1979 directory listed three repeaters in Cummings (444.7-MHz input) and one in Atlanta (444.5-MHz input), we do

not know the current status of these or other repeaters in Georgia (Morris, 1977).

The 1982-1983 ARRL Repeater Directory listed one amateur television station (ATV) in Albany, Georgia (at 439.25 MHz). This station appears to be too far from the proposed PAVE PAWS sites to be affected.

C.3.1.1.2 Moon-Bounce. A few amateurs are engaged in weak-signal experimentation in the 432.0- to 432.1-MHz band. About 100 amateur stations communicate by moon-bounce (Baldwin, 1978); that is, they propagate signals to other stations by reflecting them off the moon, using antennas with approximately 24-dBi gains. Thus, assuming a 1-kW (60-dBm) transmitter power, the stations' effective radiated power is about 84 dBm. The effective radiated power of the higher order sidelobes for the PAVE PAWS radar is about 105 dBm (about 126 times as great as the amateurs' signals). Thus, an amateur moon-bounce link could receive moon-bounce interference from PAVE PAWS when the moon is visible to both of the amateur stations involved and to a face of PAVE PAWS. Because of PAVE PAWS frequency hopping, the moon-bounce experimenters would receive 1/24th of the PAVE PAWS pulses.

C.3.1.1.3 The OSCAR Satellite. The amateurs are authorized to use satellite transponders in the 435- to 438-MHz band. Currently, only one U.S. amateur satellite remains in near-polar orbit--OSCAR 8 (Orbiting Satellite Carrying Amateur Radio). Table C-2 lists parameters describing its orbit and frequencies (Kleinman, 1978; Harris, 1978; Glassmeyer, 1978). OSCAR transmits information on the condition of its batteries and other subjects. OSCAR 8's two linear transponders accept single-sideband voice or code signals in one band and retransmit them in another. Oscar 8's "Mode J" transponder transmits within the PAVE PAWS band.

When it is within the line of sight, the radar illuminates the satellite in the same way it does the aircraft discussed in Section C.2.1. Radar energy reflected from the moon could also illuminate the satellite as well as the amateurs' ground stations.

No analysis of the susceptibility of the OSCAR satellite and the ground receivers to the PAVE PAWS is included here, although amateurs are said to be "carefully studying the problem" (Ham Radio Magazine, 1978). As yet, the OSCAR satellite is not heavily used, partly because the required equipment (particularly for receiving OSCAR 8's 435-MHz downlink) is not widely available (Kleinman, 1978).

Because the satellite's orbits are known, programming PAVE PAWS frequency usage (consistent with operational requirements) may be possible; the PAVE PAWS frequencies that would interfere with a satellite's transponder would not be used when the satellite was visible. It may also be possible, when operational requirements permit, to avoid use of the 432-MHz frequency when the moon is visible, to preclude interference to moon-bounce communications.

Table C-2

CHARACTERISTICS OF OSCAR 8,
THE ONLY CURRENTLY ORBITING U.S. AMATEUR SATELLITE

Parameter	Value
Orbit period (min)	103
Orbits per day	14.0
Maximum time per orbit within view of PAVE PAWS (min)	17
Altitude (km)	900
Inclination (deg)[a]	99
Frequencies (MHz)	
"Mode A"	
Uplink	145.85-145.95
Downlink	29.4 - 29.5
"Mode J"	
Uplink	145.9-146.0
Downlink	435.1-435.2
Telemetry beacons	29.402, 435.095

[a]Inclination is the angle between the orbit's track and the equator. Zero degrees describes an equatorial orbit, with the satellite moving east; 90 deg is a polar orbit. Angles greater than 90 deg imply that the satellite moves west.

C.3.1.2 Interference to Television

C.3.1.2.1 The Television Environment. In the United States, television is broadcast in two frequency bands. The VHF TV channels, those from channels 2 through 13, occupy portions of the spectrum between 54 MHz and 216 MHz; the UHF channels, those from channels 14 through 69, occupy the continuous spectrum between 470 MHz and 806 MHz. PAVE PAWS, then, occupies the spectrum between the VHF and the UHF TV bands.

When applying for r license to operate, a TV station has engineers calculate and provide contours of predicted TV signal strength that define the station's intended coverage area. These predictions are statistical, however, because they cannot take into account such variables

as terrain, location, and equipment that affect the reception. At the Grade A contour, by definition, the median field strength at a standard 30-ft antenna height must provide service that the median observer considers "acceptable" at least 90% of the time using an antenna equivalent to a half-wave dipole (i.e., a rabbit-ear antenna) at the best 70% of the receiving locations. At the more distant Grade B contour, the median field strength at the 30-ft antenna height must provide the median observer with "acceptable" TV reception, but only at the best 50% of the receiving locations and only if an antenna with a gain 6 dB higher than that of a dipole is used. (Such an antenna would probably be a multi-element Yagi.) The locations for the two contours are determined using FCC-approved methods to predict the signal strengths.

Increasingly, cable TV systems are used to provide TV service to subscribers who pay a monthly subscription cost. Although each cable system is likely to be unique, three major sources are used for programming:

(1) Reception of TV broadcasts directly off the air, but typically using a higher tower and better antennas than the home viewer has available

(2) Terrestrial microwave links from distant cities

(3) Geostationary satellites.

C.3.1.2.1.1 <u>The Television Environment Near Robins AFB</u>. The area of Warner Robins and Robins AFB is about 10 miles south of Macon, about 100 miles southeast of Atlanta, and about 70 miles northeast of Columbus--all of which are sources of broadcast television programming. Table C-3 lists the TV channels known to be received "off the air" in the area. These channels are most likely to be available to home TV viewers, depending on location and height and quality of antenna system. Local conditions or situations may exist that prevent one or more of these stations from being received or that allow some other station, not listed here, to be received.

Although some TV viewers in the Warner Robins/Robins AFB area receive broadcast TV signals directly using their own antennas, approximately 15,000 TV households in the area subscribe to the cable service provided by Cox Cable of Warner Robins. The system provides service both on and off the base and is said to have achieved greater than 80% saturation of the local market.

The Cox Cable system has a single receiving location that is about 3.5 miles behind the proposed PAVE PAWS site. Cox Cable uses a 350-ft tower to support its antennas for receiving FM and TV broadcast signals and TV signals arriving by terrestrial microwave systems. The TV broadcast signals are generally received using antennas not unlike those that might be used at home. However, a high-gain 8-ft dish is used to receive WTBS, channel 17, from Atlanta. In addition, narrow-band preamplifiers are placed on the tower near the antennas for that channel

Table C-3

TV CHANNELS RECEIVED IN THE VICINITY OF ROBINS AFB[a]

TV Channel	Call Sign	Band (MHz)	Origin	Contour Grade in the Local Area
3	WRBL	60-66	Columbus	B
9	WTVM	186-192	Columbus	B
11	WXIA	198-204	Atlanta	beyond B
13	WMAZ	210-216	Macon	A
15	WDCO	476-482	Cochran	?
17	WTBS	488-494	Atlanta	?
24	WGXA	530-536	Macon	A
41	WCWB	632-638	Macon	A
46	WANX	662-668	Atlanta	?

[a]This includes broadcast TV signals picked "off the air" by Cox Cable, but excludes those brought into the area by terrestrial microwave systems or satellite.

and for WTVM, channel 9, from Columbus. A ground-level parabolic dish antenna is used for reception of TV signals that arrive by satellite. All these TV and FM signals are put onto the cable system for distribution to subscribers.

The TV frequencies distributed to the subscribers' TV receivers are generally different from those received by the cable system; they are all VHF frequencies. Table C-4 describes the frequency translations that are done at the receiving site. As examples, channel 9 remains in the 186-192 MHz band, but channel 41 is translated from its UHF band (632-638 MHz) to the channel 6 position (82-88 MHz). Several TV channels (e.g., CINEMAX, HBO, Atlanta's channel 46) are translated to VHF frequencies not accessible to the normal TV receiver. The spectrum space for about 14 TV channels between channel 6 and channel 7 is used for cable programming and made available to the subscriber through a special frequency converter on the TV set that converts these "midband" signals to the channel 3 frequency band.

The distribution system uses mostly aboveground coaxial cable, with amplifiers spaced appropriately. About 80% of the more than 300 miles of distribution cable is overhead and the rest is underground. The cable carries all of the VHF TV signals (including several midband channels between channels 6 and 7) at the frequencies to which they have been translated.

Table C-4

RECEPTION AND DISTRIBUTION OF CABLE TV CHANNELS
NEAR ROBINS AFB

Channel (As Distributed)	Frequency Band (MHz)	Call Sign	Mode of Reception
2	54-60	WGXA	Broadcast TV Ch. 24 from Macon
3	60-66	WRBL	Broadcast TV Ch. 3 from Columbus
4	66-72	WMAZ	Broadcast TV Ch. 13 from Macon
5	76-82	CNN	Satellite
6	82-88	WCWB	Broadcast TV Ch. 41 from Macon
D[a]	138-144	CINEMAX	Satellite
E[a]	144-150	WANX	Broadcast TV Ch. 46 from Atlanta
G[a]	156-162	HBO	Satellite
I[a]	168-174	Spotlight	Satellite
7	174-180	WTBS	Broadcast TV Ch. 17 from Atlanta
8	180-186	WDCO	Broadcast TV Ch. 15 from Cochran
9	186-192	WTVM	Broadcast TV Ch. 9 from Columbus
10	192-198	ESPN	Satellite (or land-based microwave)
11	198-204	WXIA	Terrestrial microwave
12	204-210	Robins Bulletin Board (local origination)	
13	210-216	Approximately 20 FM stations	

[a]These channels are carried on the cable at the frequencies shown and are translated to the channel 3 band by the subscriber's converter.

C.3.1.2.1.2 The Television Environment Near Moody AFB. The region including Moody AFB and Valdosta is about 75 miles southeast of Albany, 70 miles northeast of Tallahassee, and about 60 miles southwest of Waycross. TV stations in these cities and the one in Valdosta are the major sources of broadcast programming available near Valdosta and Moody AFB. Table C-5 lists the TV channels most likely to be received by home TV viewers using their own antenna systems. Home TV viewers may not receive all of these stations. Reception depends strongly on local terrain and on the height and quality of the receiving antenna system.

Table C-5

TV CHANNELS RECEIVED IN THE VICINITY OF MOODY AFB[a]

TV Channel	Call Sign	Band (MHz)	Origin	Contour Grade in the Local Area
6	WCTV	82-88	Tallahassee	B
8	WXGA	180-186	Waycross	?
10	WALB	192-198	Albany	B
27	WECA	548-554	Tallahassee	?
44	WVGA	650-656	Valdosta	A

[a]This includes broadcast TV signals picked "off the air" by the two cable systems, but excludes those brought into the area by terrestrial microwave systems or satellite.

There is a cable TV system in Valdosta and one in the immediate vicinity of Moody AFB: Group W Cable, a subsidiary of Westinghouse, serves the city of Valdosta; Jones Intercable (formerly Moody Cable TV) serves Moody AFB, as well as subscribers along Highway 125 from about 0.5 mile south of the base to 3 miles north of it.

The Group W system in Valdosta has approximately 12,500 subscribers and claims 70% to 80% of the available market there. The system has about 250 miles of cable, about 90% of which is aboveground. The receiving system includes a 350-ft tower at the western edge of the city. It supports dish antennas for reception of TV signals that originate in Atlanta and are relayed over a series of point-to-point microwave links, as well as antennas for the five broadcast TV channels that the system picks off the air. There are two dish antennas at ground level for reception of satellite TV--one for each of two satellites. Table C-6 shows which broadcast TV channels the system receives and, in some cases, how their frequencies are translated. These channels, as well as three channels received by the terrestrial microwave link and approximately ten satellite channels, are translated into the VHF band (which includes the nine "midband channels," A through I, that occupy 120 MHz to 174 MHz between TV channels 6 and 7). Translators at the subscribers' homes convert the midband channels to frequency bands that the TV receiver can use.

The Jones Intercable (Moody) system is much smaller, but much closer to PAVE PAWS. It serves approximately 1,100 subscribers, including about 90% of the base housing at Moody AFB. The receiving system's antennas are on a 165-ft water tower on Moody AFB, about 3.3 miles behind the proposed PAVE PAWS site. Narrow-band preamplifiers are used for two of the TV channels received from regular broadcasts--channels 6 and 27,

Table C-6

CABLE TV CHANNELS ORIGINATING AS BROADCAST TV AND DISTRIBUTED IN VALDOSTA BY GROUP W

Channel (As Distributed)	Frequency Band (MHz)	Call Sign	Mode of Reception
6	82-88	WCTV	Broadcast TV Ch. 6 from Tallahassee
G[a]	156-162	WECA	Broadcast TV Ch. 27 from Tallahasse (Sometimes Ch. 27 is translated to Ch. 7.)
7	174-180	WVGA	Broadcast TV Ch. 44 from Valdosta
8	180-186	WXGA	Broadcast TV Ch. 8 from Waycross
10	192-198	WALB	Broadcast TV Ch. 10 from Albany

[a]This midband channel is carried on the cable at the frequency shown and is translated to a channel compatible with a standard TV receiver by the subscriber's converter.

both from Tallahassee. A satellite dish is at the base of the water tower. Table C-7 shows the channels and sources of programming distributed by this system.

C.3.1.2.2 Television Receiver Susceptibility to Interference. Degradation to TV reception is said to occur when an observer can detect the effect of the interfering signal. Interference with the video portion generally occurs first; that is, the video effect is usually perceptible at lower interfering-signal levels than are required for a perceptible audio effect.

Before the PAVE PAWS radars at Otis ANG Base and Beale AFB became operational, only very limited tests had been conducted using real and simulated PAVE PAWS signals to determine their ability to interfere with TV reception. MITRE had experimented with simulated PAVE PAWS signals, using three monochrome TV receivers and one color TV receiver. They also operated a small, portable, battery-operated, black-and-white TV receiver in the vicinity of the East Coast PAVE PAWS at Otis ANG Base (MITRE, 1978). MITRE's work with the simulated signals corroborates other results described in this report. They were able to operate that particular portable set within 3,400 ft of PAVE PAWS (although the set was probably shielded by heavy vegetation) without noticeable degradation to the channel 10 signal. They also observed TV reception at two motels in Sandwich within about 2 miles of the radar and could see no interference. That town was better shielded by both terrain and foliage than are the West Coast communities in front of the radar at Beale AFB.

Table C-7

CABLE TV CHANNELS DISTRIBUTED IN THE MOODY AFB AREA

Channel (As Distributed)	Frequency Band (MHz)	Call Sign	Mode of Reception
2	54-60	FM music	Broadcast from various locations
3	60-66	"The Movie Channel"	Satellite
4	66-72	WTBS	Satellite from Atlanta
5	76-82	HBO	Satellite
6	82-88	WCTV	Broadcast TV Ch. 6 from Tallahassee
7	174-180	WGN	Satellite from Chicago
8	180-186	WXGA	Broadcast TV Ch. 8 from Waycross
9	186-192	WVGA	Broadcast TV Ch. 44 from Valdosta
10	192-198	WALB	Broadcast TV Ch. 10 from Albany
11	198-204	ESPN	Satellite
12	204-210	WECA	Broadcast TV Ch. 27 from Tallahassee
13	210-216	CBN	Satellite

Since the first two PAVE PAWS radars have become operational, more has been learned about the type and extent of interference to TV reception. The situation is vastly different in the areas surrounding PAVE PAWS on the East Coast and the West Coast. At Otis ANG Base, 700 to 800 instances of TV interference from the PAVE PAWS radar have occurred; at Beale AFB, only 4 or 5 instances have been noted. In all instances, the problem has been saturation of a preamplifier as described in the next subsection. The Air Force has developed a filter that can prevent this interference and has installed it at Air Force expense wherever valid complaints of TV interference by PAVE PAWS have been made.

C.3.1.2.2.1 Saturation Responses. Tests by Conklin (1974) suggest that strong signals in the PAVE PAWS frequency band can affect TV reception. The pulse width of the interfering signal apparently does not make much difference in the interference threshold. Conklin describes the appearance of (nonsaturating) pulsed interference as dashes appearing at the beginning and at the end of the pulse, saying that "nothing is visible during the remaining period that the pulse is on, since the steady-state portion is regarded by the receiver the same as a CW signal is." Thus, a nonsaturating pulse provides two groups of dashes at widely separated parts of the TV screen. If the interfering signal is strong enough to saturate the TV receiver, however, the pulse width is important because the pulse wipes out the picture for an instant between the two groups of dashes.

Because of the PAVE PAWS "PRF" and the frequency offset from the TV channels, strong PAVE PAWS signals could saturate a TV receiver. Conklin (1974) says that the saturation response level is relatively insensitive to the level of the TV signal itself and that saturation will occur at an interference power level of approximately 12 mW (+11 dBm) at the receiver. No information was given on how many TV sets were examined to obtain that number or on how many viewers were used as subjects.

The power level at the receiver terminals can be related to the corresponding electromagnetic field power density by considering the TV antenna's effective aperture and accounting for some loss in the feedline. The effective receiving area, a, of an antenna is directly proportional to its gain, g. (See p. 25-28 of Reference Data for Radio Engineers, 1973.) At a frequency of 435 MHz (the middle of the PAVE PAWS band), the aperture is approximately $a = 0.038g\ m^2$.

In the areas immediately surrounding both potential PAVE PAWS sites, the major TV stations are located in various directions from the radars. As a result, identifying the typical pointing directions of the TV receiving antennas in the vicinities of the two proposed radar locations is not possible. The circularly polarized and far out-of-band PAVE PAWS signal might hit the horizontally polarized TV antenna from the front, the back, or the side. Because antenna gain for such an unclearly defined situation cannot be specified, we estimated that the average gain will be that of an isotropic antenna (i.e., $g = 1$). In that case, the receiving area would be about $a = 0.038\ m^2$. Power density and power at the receiver terminals are typically expressed in decibels; a similar expression for the receiving area is

$$A = 10 \log a = -14.2 \text{ dB relative to } 1\ m^2 \quad .$$

The power density (in dBm/m^2) corresponding to some known power at the TV receiver (in dBm) can now be estimated by adding 14.2 dB for the aperture plus about 2 dB to account for losses in the antenna lead (O'Connor, 1968). Applying this method to the 11-dBm saturation level of Conklin (1974) yields an equivalent field of $11 + 14.2 + 2 = 27.2$ dBm/m^2, which is quite close to the power density levels found for threshold high-power effects.

Experience at Otis ANG Base and Beale AFB has shown that at least two TV receiving antenna systems are susceptible to interference from the PAVE PAWS signal because of their design. Each of these antenna systems, designed for use with the weak signals found in fringe reception areas, includes a preamplifier mounted on the antenna structure. The preamplifier is intended to amplify both VHF TV signals (which are in the spectrum extending from 54 MHz to 216 MHz) and UHF TV signals (which occupy the spectrum above 470 MHz). It is not designed, however, to reject signals in the spectrum between VHF and UHF TV, which includes the PAVE PAWS signal (420-450 MHz).

The preamplifier is designed to work with relatively weak TV signals; when a relatively strong PAVE PAWS pulse is coupled into the

preamplifier by the antenna, the preamplifier can be driven into saturation. When that occurs, its gain decreases so dramatically that it is, in effect, turned off. Because each PAVE PAWS pulse that is strong enough to saturate the preamplifier will, in effect "turn off" the TV signal on all channels, the TV screen will be blanked for a considerable percentage of the time. A cluster of long-range surveillance pulses, for example, would affect the screen for about 16 ms per 66-ms resource, or for about 25% of the time, blanking every other horizontal line on the 525-line screen during that time. Because no measurements have been made to determine the level of the PAVE PAWS signal that produces this effect, we cannot predict where it will occur.

C.3.1.2.2.2 Spurious Responses. A receiver can accept and process signals at frequencies far from the one to which it is tuned. Such an action is called a spurious response; the interfering frequency that produces it is called a spurious response frequency. Spurious response frequencies, f_{sr}, are found by solving the equation:

$$f_{sr} = \text{abs} \frac{pf_{LO} \pm f_{IF}}{q}$$

where f_{LO} = the receiver's local oscillator frequency (about 44 MHz higher than the center of the TV channel)

f_{IF} = the receiver's intermediate frequency

p,q = integers denoting the harmonics of the local oscillator and the interfering frequency, respectively

and abs indicates the absolute value of the expression.

PAVE PAWS frequencies can cause spurious responses in TV receivers. The TV receiver IF passband extends from 41 to 47 MHz. When we set p = 2 and q = 1, we are, in effect, searching for strong external signals that can mix with the second harmonic of the local oscillator, so that the difference frequency falls within the IF passband and is amplified as if it were part of the desired TV signal. Figure C-2 shows that VHF channels 9 through 11 are potentially susceptible to spurious responses of the p = 2, q = 1 type caused by PAVE PAWS. Higher order spurious responses in the VHF TV band may also occur, but only when the levels of the interfering signal are much higher. Channels 9 and 10 will be of concern because one is used in each of the two PAVE PAWS areas, whereas channel 11 is not. Spurious responses for p = 1, q = 2 would also occur on UHF TV channels 60 through 83, but those TV channels are not in use in the vicinity of PAVE PAWS.

The spurious response of 12 color TV receivers was measured for channel 10; the results show a large range in the susceptibility thresholds of various TV receivers (see Figure C-3). The two curves indicate the mean susceptibility level and a level for the more susceptible receivers. No data were provided for the less susceptible half of the sample. The interfering signal had pulse widths of 100, 200, and 1,000 microseconds, with a PRF of 40 pps. Although the

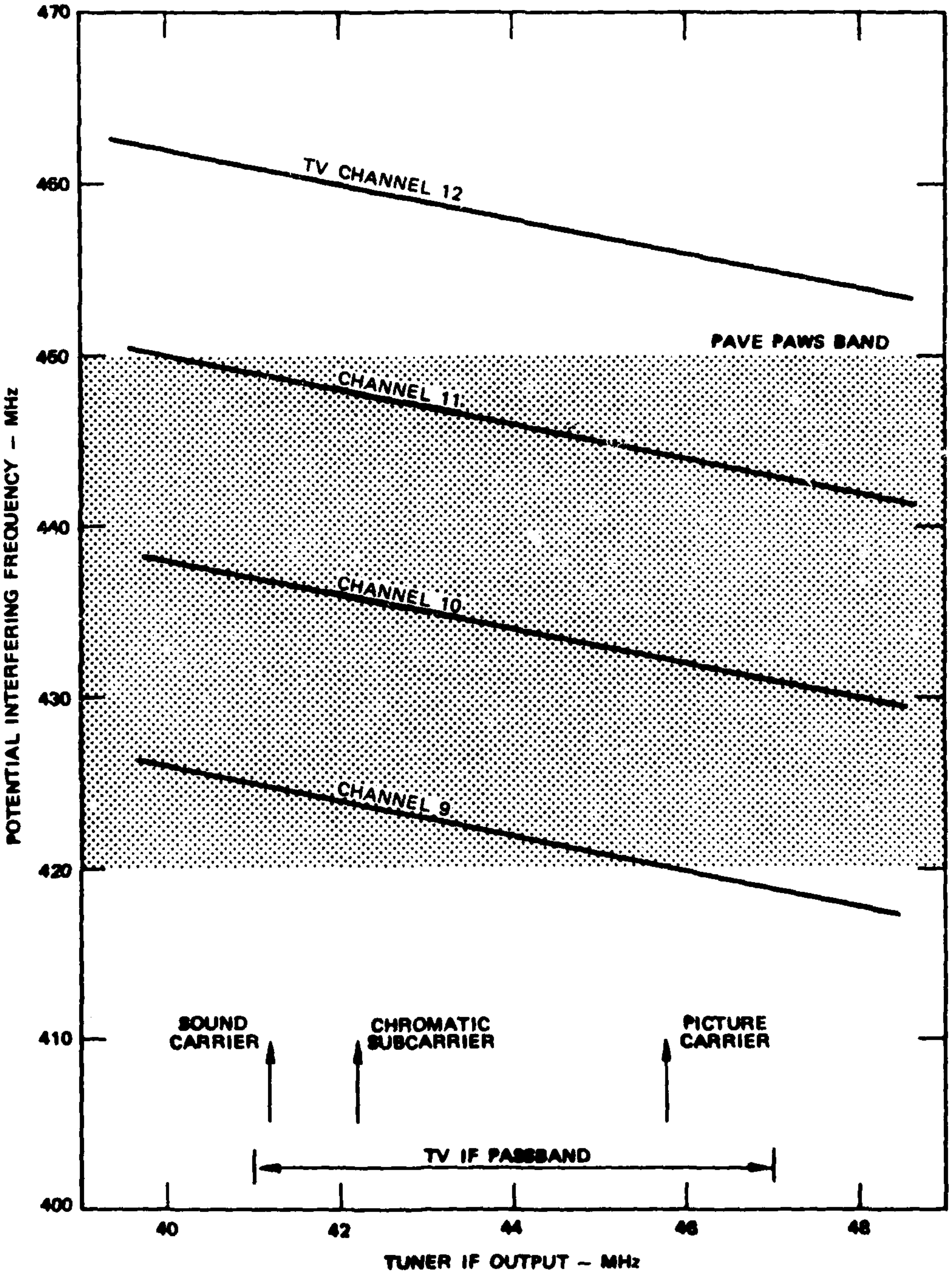


FIGURE C-2 TELEVISION RECEIVER SPURIOUS-RESPONSE FREQUENCIES IN AND NEAR THE PAVE PAWS BAND ($p = 2, q = 1$)

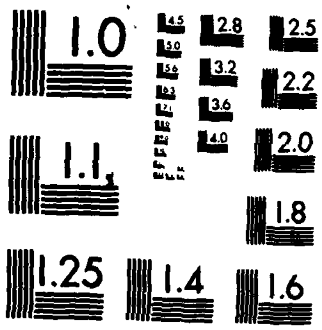
AD-A129 370 SOUTHEAST PAVE PAWS RADAR SYSTEM ENVIRONMENTAL ASSESSMENT(U) SRI INTERNATIONAL MENLO PARK CA S J EVERETT ET AL. MAR 83 SAM-TR-83-7 F33615-82-C-0604 4/4

UNCLASSIFIED F/G 6/19 NL

END

DATE FILMED

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

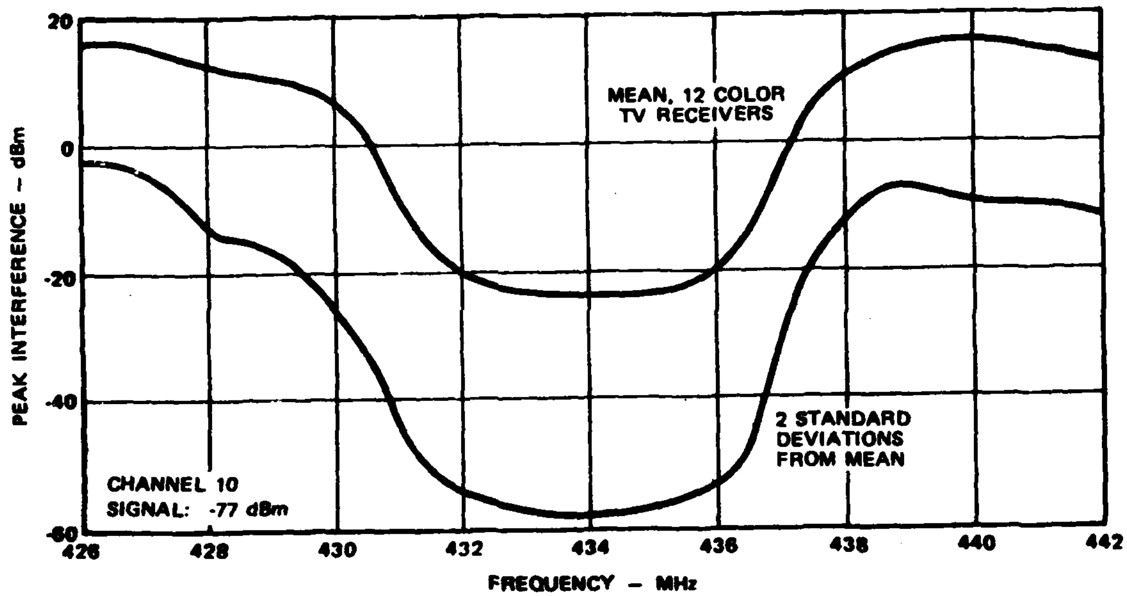


FIGURE C-3 TV CHANNEL-10 INTERFERENCE THRESHOLD FOR p = 2, q = 1 SPURIOUS RESPONSE

frequencies involved are the same as those of PAVE PAWS, this information does not permit us to predict whether higher or lower thresholds of susceptibility would result from using the actual PAVE PAWS signal, with its mix of pulse widths and its unusual PRF. The measurements represented by Figure C-3 were made at a TV signal level of -77 dBm at the TV receiver terminals. Figure C-4 shows how the pulse interference threshold increases as TV signal strengths increase.

C.3.1.2.2.3 High-Power Effects. High-power effects result when a strong signal couples power directly into a system's internal circuitry and components. Measurement programs using PRF and pulse widths of a radar system somewhat similar to PAVE PAWS have been conducted to determine power density thresholds for high-power effects for TV receivers. In one program, five black-and-white and two color TV sets, all made in or before 1967, were used. Mean power density thresholds were found to be about 30 dBm/m^2 (0.1 mW/cm^2), independent of the level of the desired TV signal. Use of a preamplifier with the TV antenna resulted in threshold susceptibility levels about 10 dB lower. (Some of these data have recently become more widely available; see Donaldson, 1978).

In another program, 45 TV receivers (1970 models, 15 monochrome and 30 color) were used. At the PAVE PAWS frequency, the mean susceptibility threshold was about 24 dBm/m^2. This work was done at a PRF of 300 pps with a pulse width of 10 microseconds; PAVE PAWS signals may be less disruptive. The data included in Table C-8 were reported and, although the measurement conditions used to obtain those data were not specified, the frequency band (420 to 450 MHz) is appropriate. Another program reports that for TV channels below 18, most of the degradation results from antenna-coupled interference.

Table C-8

INTERFERENCE THRESHOLD LEVELS FOR VHF TV VIDEO HIGH-POWER EFFECTS FROM SIGNA[illegible] IN THE PAVE PAWS BAND [dBm/m^2 and (mW/cm^2)]

	Threshold			
	Worst Case		Mean	
Wide-band response	18	(0.0063)	29.4	(0.087)
Spurious response	-29	(0.00000013)	-7.3	(0.000019)

Note: dBm/m^2 = decibels above 1 mW/m^2.

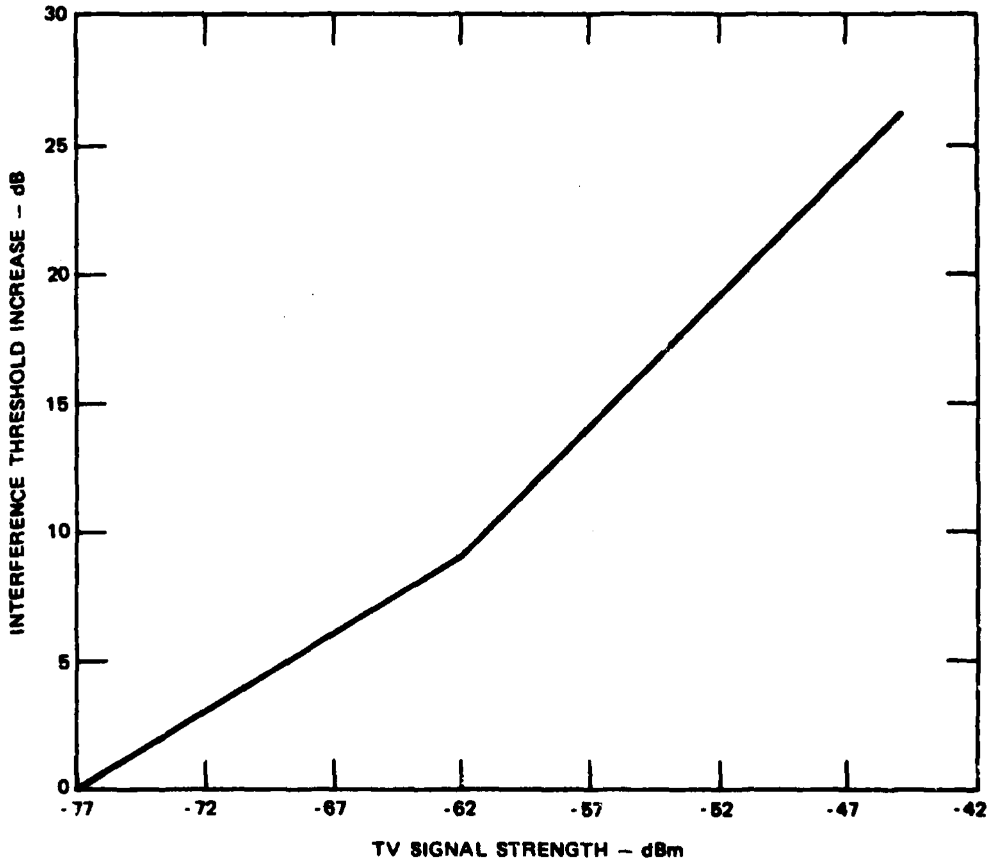


FIGURE C-4 INTERFERENCE-THRESHOLD INCREASE FACTOR FOR TV SIGNAL STRENGTH HIGHER THAN -77 dBm

C.3.1.2.2.4 TV Receiver Susceptibility to PAVE PAWS Signals. On the basis of the preceding analysis, our best estimate is that reception of VHF TV channels could be affected by PAVE PAWS signals greater than about 11 dBm at the antenna terminals (or a power density of about 27 dBm/m^2), regardless of the strength of the desired TV signal. Because of the spurious response mechanism, channel 10 will be particularly sensitive to PAVE PAWS signals in the 431- to 437-MHz frequency range; channel 9 will be similarly sensitive to those in the 420- to 425-MHz range. The effect is more pronounced when the signal-to-interference level is lower.

The TV receiver susceptibilities are best compared in terms of electromagnetic field quantities. The high-power effects presented in Table C-8 are already in power density terms. With the procedure discussed in Section C.3.1.2.2.1, the 11-dBm saturation threshold suggested by Conklin (1974) is converted to approximately 27 dBm/m^2 (0.05 mW/cm^2) as the equivalent field power density.

The same conversion can be applied to the vertical scale of Figure C-3, to determine that the 434-MHz power density that would affect the more susceptible half of the TV receivers by producing the spurious response is about $-24 + 16 = -8$ dBm/m^2 (0.000016 mW/cm^2) when the desired channel 10 signal strength (at the receiver terminals) is -77 dBm. Presumably, similar results would be obtained at about 422 MHz for channel 9.

Because the concern with spurious response principally revolves around reception of TV channels 9 through 11 in the vicinity of a PAVE PAWS radar, the two candidate areas are discussed separately. In the vicinity of Moody AFB, the channel 10 signal strength is needed. According to the Television Factbook (1974), the area surrounding Moody AFB is about halfway between the Grade A and Grade B contours for WALB channel 10 from Albany. That means that the median predicted TV field strength there is approximately $E = 64$ dB above 1 microvolt/m (0.0016 V/m). O'Connor (1968) relates the field strength to the voltage, V_L, across the receiver terminals, by

$$V_L = E + K_d + G - L \quad \text{dB above 1 microvolt}$$

where V_L and E are already defined, L is the loss in the antenna lead, G is the TV antenna gain in decibels relative to a dipole, and K_d is called a dipole factor. For the channel 10 frequency band (192 to 198 MHz), $K_d = -6$ dB. The line loss will be about 2 dB and the gain of a typical good Yagi antenna will be about 9 dB relative to a dipole. Therefore, the median value of V_L is about

$$V_L = 64 - 6 + 9 - 2 = 65 \text{ dB above 1 microvolt} = 1{,}800 \text{ microvolts},$$

and the power level of WALB at the 300-ohm terminals is about

$$\frac{(1{,}800 \text{ microvolts})^2}{300} = 1.1 \times 10^{-5} \text{ mW} = -49 \text{ dBm}.$$

Figure C-4, which gives the TV signal strength correction factor for Figure C-3, indicates that for a TV signal strength of -49 dBm, we must increase the channel 10 spurious signal susceptibility by about 23 dB. Therefore, about half of the TV sets would display some perceptible effect when the PAVE PAWS power density is about -8 dBm/m^2 + 24 dB = 16 dBm/m^2 (0.004 mW/cm^2). Figure C-3 indicates that the most susceptible TV sets may be affected by PAVE PAWS signals about 35 dB lower, or at about -19 dBm/m^2.

The channel 10 spurious response frequencies lie in the band from 431 to 437 MHz. Six of the 24 PAVE PAWS frequencies (see Table A-1), can therefore produce that spurious response. The channel 10 response to the other 18 PAVE PAWS frequencies would be the same as that of the other TV channels. Therefore, only one-third of the radar pulses have a frequency that can cause that spurious response.

In the Robins AFB area, the spurious response would occur, if at all, while the TV receiver is tuned to WTVM, channel 9 from Columbus. Because the Robins AFB area is approximately on the station's Grade B contour, the median predicted field strength is about 56 dB above 1 microvolt/m (0.00063 V/m). Calculated by using the above procedure, the voltage at the receiver terminals is about V_L = 710 microvolts, and the corresponding power level is about -58 dBm. Reference to Figure C-4 shows that the susceptibility increases by about 13 dB for a TV signal strength of -58 dBm. Thus, about half of the TV receivers would show some effect at a PAVE PAWS power density of about -8 dBm/m^2 + 13 dB = 5 dBm/m^2 (0.00032 mW/m^2). As before, the most susceptible TV sets may be affected by PAVE PAWS signals about 35 dB weaker, or at about -30 dBm/m^2. The channel 9 spurious response frequencies are in the band from about 418 to 425 MHz; thus, given a sufficiently strong PAVE PAWS signal, only four of the 24 PAVE PAWS frequencies could produce this effect.

C.3.1.2.3 Effects of PAVE PAWS on TV Reception

C.3.1.2.3.1 Effects on TV in the Vicinity of Robins AFB. According to Section B.8 (Appendix B), certain areas in front of PAVE PAWS (i.e., within the 248-deg sector A illustrated in Figure B-1) are sometimes illuminated by the radar's second sidelobe. Among these are the nearest residences along Old Hawkinsville Rd. and along Highway 129 just south of Sandy Run. In all directions (including behind the radar), the radar's higher order sidelobes or diffraction and scattering will cause illumination. No areas receive main-beam or first-sidelobe energy. Figure C-5 shows the decrease in pulse power density as a function of distance from the radar. The curves in the figure are all reduced from their free-space values by a factor of 10 dB to account for the attenuation caused by the very tall trees and the heavy foliage that extend in all directions from the radar. Because 10 dB is a very conservative estimate of the attenuation, the power density will likely be considerably less than indicated here (see Appendix B, Section B.5.1).

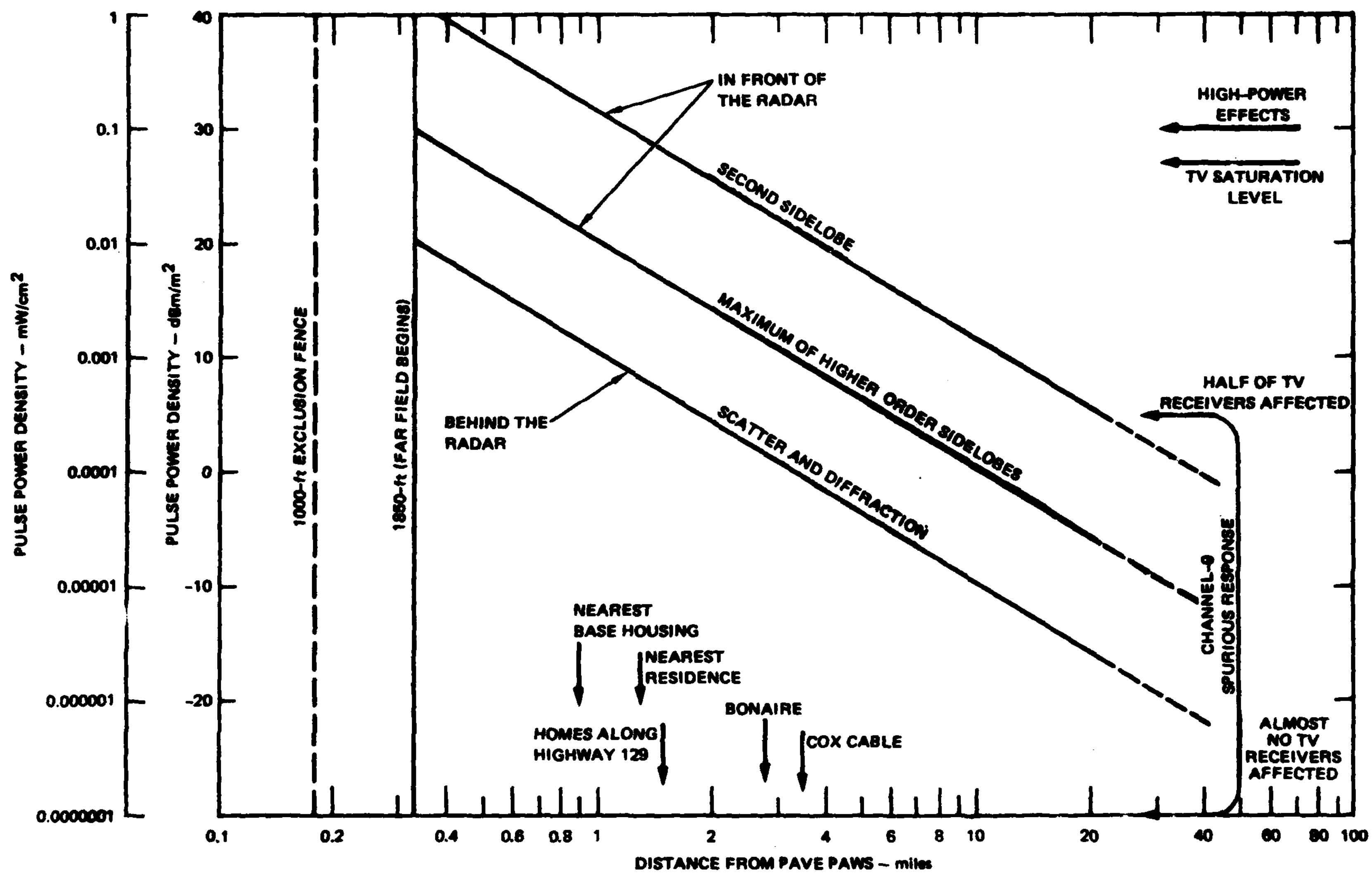


FIGURE C-5 PAVE PAWS SIGNAL STRENGTH AND POSSIBLE EFFECTS ON TV RECEPTION — ROBINS AFB

The available data are sufficient to suggest a potential problem for a limited number of TV receivers, but not sufficient to define the extent of the problem clearly. The heavy trees may reduce the PAVE PAWS signal much more than the 10 dB assumed here. It was shown in Section C.3.1.2.2.1 that TV receivers would exhibit their saturation response on most channels if the PAVE PAWS signal reached levels of about 27 dBm/m^2 (0.05 mW/cm^2) and that high-power effects would occur for only slightly higher levels. Figure C-5 shows that TV receivers in the nearest residences in front of the radar, which are about 1.3 to 1.5 miles away, appear to receive high enough second-sidelobe energy to subject them to interference caused by either saturation or high-power effects. On the other hand, the much closer base housing is behind the radar and receives only scattered and diffracted energy, so high-power or saturation effects are not likely there. The entire base and the city of Warner Robins are behind the radar and even farther away. Bonaire, although in front of the radar, is far enough away so that the probability of these types of interference is quite low. Although saturation effects would be expected only on receivers using their own antennas, high-power effects could be coupled into the receiver through the case. This may affect even TV receivers that are connected to the cable TV system (if the cable system extends that far) in the homes along the highway in front of the radar.

The range of thresholds for the channel 9 spurious response is also shown in Figure C-5. (The threshold of susceptibility varies greatly from one TV receiver to another.) Figure C-3 and subsequent discussion suggest that about half of the TV receivers would be affected by PAVE PAWS levels of about 5 dBm/m^2 (0.00032 mW/cm^2) and above, and that the most susceptible TV receivers would be affected by PAVE PAWS signals 35 dB lower, or -30 dBm/m^2 (0.0000001 mW/cm^2). (The four sets tested by MITRE (1978) in their laboratories fall toward the more susceptible end of this range.) As shown in Figure C-5, if they are receiving a relatively weak channel 9 signal, the most susceptible TV receivers might be affected at distances greater than 100 miles in front of the radar, or even behind it.

Despite such gloomy predictions, which are based on the laboratory measurements of a small number of TV receivers and on estimates of the strengths of the TV and the PAVE PAWS signals, the situation may not be that bad. Similar predictions were made for the vicinity of Beale AFB, where the PAVE PAWS first sidelobe illuminates the Marysville/Yuba City area at a distance of about 12 miles. Even without the benefit of any intervening vegetation to produce attenuation, no problems were reported of spurious response interference with a channel 10 signal.

For the approximately 15,000 households in the Warner Robins area that subscribe to cable TV, the effects of PAVE PAWS will depend on the susceptibility of the Cox Cable receiver that receives the broadcast channel 9 signal directly. If this receiver exhibits a spurious response to the PAVE PAWS signal, that spurious response will be sent to all subscribers.

The Cox Cable receiving system is about 3.5 miles behind the radar, so that it would be hit only with scattered and diffracted energy at a level about 30 dB lower (1,000 times lower) than that believed to be required for high-power interference effects. Figure C-5 indicates that the channel 9 spurious problem could occur at that distance, but this could be treated quite easily if it were to occur.

The only available data on the thresholds of susceptibility of TV receivers to spurious responses from signals in the PAVE PAWS band apply to home TV receivers, not to those used by the cable TV companies. Some cable TV receivers have the same local oscillator and IF frequencies as the tuner in home TV receivers, however, so that the spurious response mechanism would be the same. High-gain antennas are used on top of a high tower at the receiving location; therefore, the TV signals at the Cox Cable receiver terminals are almost certainly considerably higher than those at home installations in the same vicinity.

Because of those differences, it would be difficult to predict, on the basis of the results of a few tests on home TV receivers, the likelihood of PAVE PAWS interference to the cable TV system. However, enough evidence exists to indicate that PAVE PAWS may cause interference to channel 9 when it is transmitting in the 420- to 425-MHz band. Fortunately, preventing the PAVE PAWS signal from entering the cable system's channel 9 receiver to cause the spurious response is not difficult, as will be discussed in Section C.3.1.2.4.

C.3.1.2.3.2 Effects on TV in the Vicinity of Moody AFB. As at Robins AFB, a limited area in front of the radar at Moody AFB would be illuminated by the second sidelobe. This includes those very few, widely scattered homes along Highway 221 (which is about 0.7 mile from the radar at its point of closest approach), as well as the city of Valdosta (which is about 10 to 12 miles from the proposed site). Figure C-6 shows the decrease in PAVE PAWS power density with distance, where again an additional 10-dB loss was added to account for propagation through the tall trees surrounding the abandoned airstrips on which the radar would be sited. The plot suggests that TV interference caused by high-power effects or by saturation would probably not occur in front of the radar at distances greater than about 2 miles.

The plot indicates that the second sidelobe might cause a channel 10 spurious response (for the most susceptible TV receivers) at distances of more than 100 miles in front of the radar. Behind the radar, where the signals arrive by scattering and diffraction, it appears that far fewer than half of the TV receivers in the Bemiss area or the base housing area could be affected. (About 90% of the base housing is on the cable system and would not be directly affected by the radar's fields in any case.) At distances beyond about 30 miles behind the radar, probably no TV receivers would be affected.

Again we point out that predictions of even more extensive interference were made for the channel 10 spurious effect in the vicinity of Beale AFB; but very little, if any, effect was noted. Marysville and

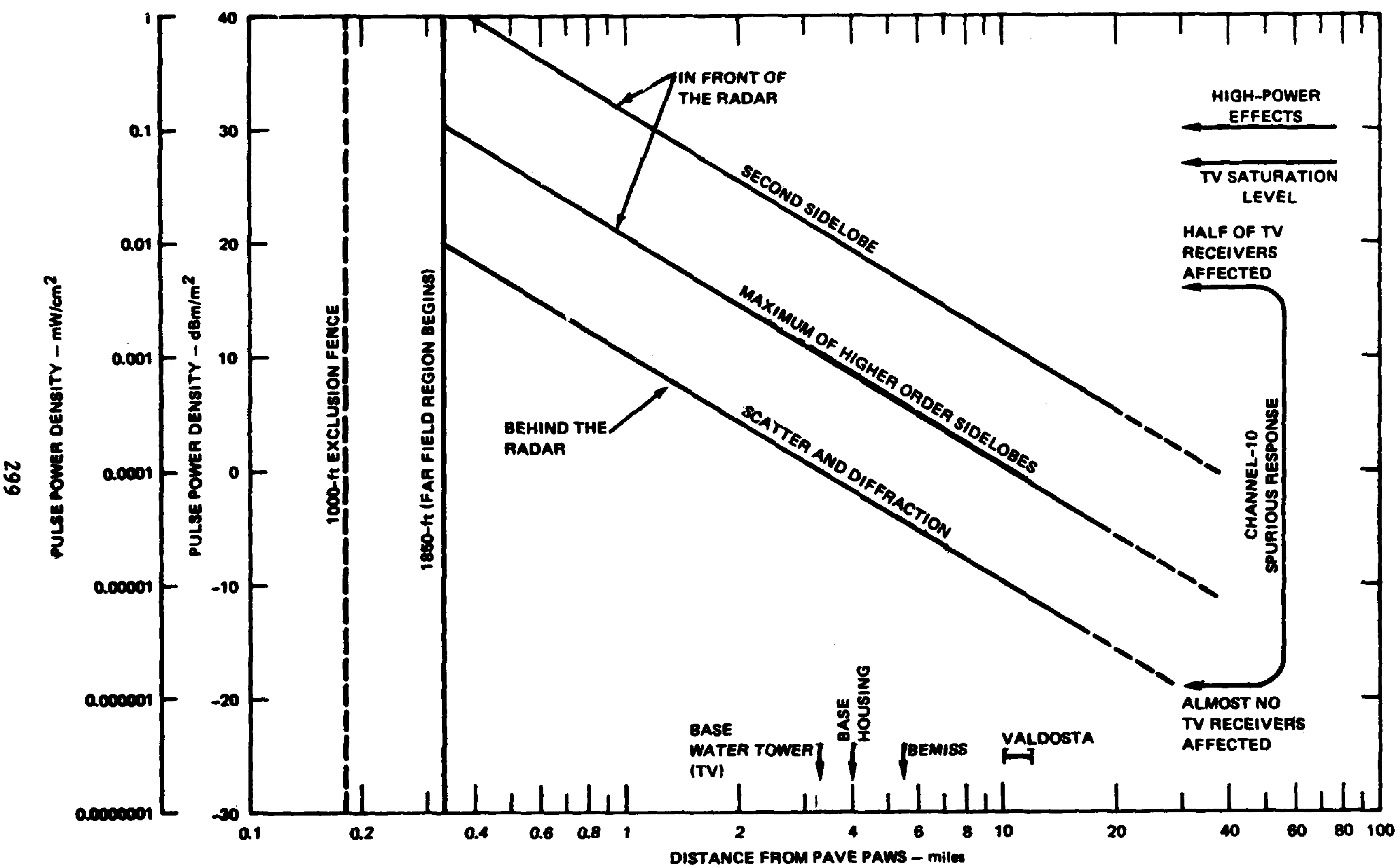


FIGURE C-6 PAVE PAWS SIGNAL STRENGTH AND POSSIBLE EFFECTS ON TV RECEPTION — MOODY AFB

Yuba City, about 12 miles away from and in front of that PAVE PAWS (as is Valdosta), are directly illuminated by that radar's first sidelobe, at about the same level as the Moody radar's second sidelobe.

The receiving antennas for the Group W cable system are about 12 miles from the radar--far enough away that high-power effects or saturation are of no concern, but not far enough to guarantee that there could be no channel 10 problem. If there is, it can easily be treated, as discussed in Section C.3.1.2.4.

The receiving antennas for the Jones Intercable (Moody) cable TV system are at about the 150-ft level of the base's large 165-ft water tower. These antennas are believed to be in direct line of sight of the back of PAVE PAWS over the trees. Thus, the power density there would be about +10 dBm/m^2 instead of about 0 dBm/m^2, as shown by the lower curve. This power density level is still more than 15 dB too low (by a factor of at least 30) to cause high-power or saturation effects. Again, however, interference caused by the channel 10 spurious problem is a possibility, and, again, this can easily be remedied.

Thus, because of the sparse population in the immediate vicinity of the front of the radar and because of the attenuation caused by the tall trees beyond the edge of the abandoned runways, very few instances of TV interference caused by PAVE PAWS should occur. Further, those problems that do arise can be handled.

C.3.1.2.4 Ways to Mitigate Interference. Although the potential exists for interference with channel 9 and channel 10 in the vicinity of SEPP, several steps can be taken to alleviate the situation.

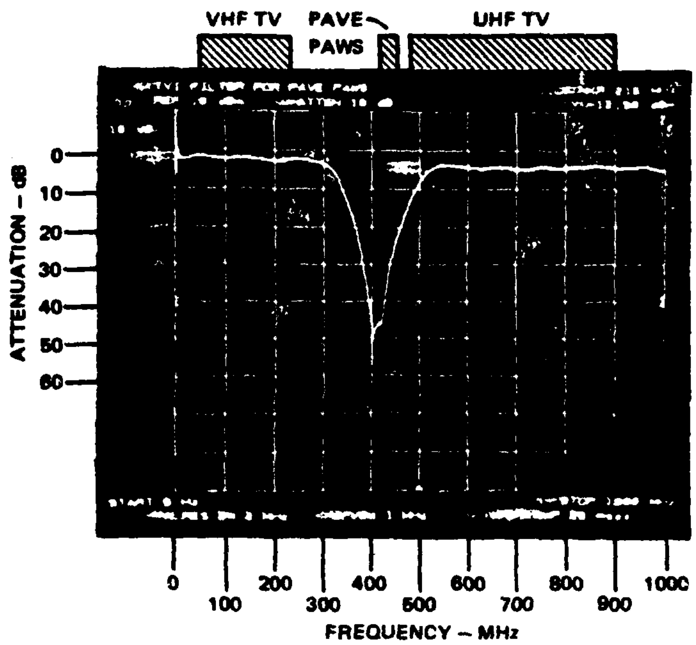
The Beale AFB analysis was based on a very limited amount of real data, developed before any PAVE PAWS radars had been built. Experience now suggests that the interference may be less severe than the analysis indicated. Only 12 TV receivers were measured in the late 1960s; PRFs and pulse widths other than those of PAVE PAWS were used, although the radar frequency band was the same. Moreover, susceptibility depends on the TV signal strength. Although the best available estimates were used for the median TV signal strengths, they could be much higher or lower in particular situations. In addition, antenna installations for cable TV systems are engineered to provide higher signal strengths to the receivers than do most home antennas. Furthermore, the attenuation of the PAVE PAWS signal through heavy foliage may be greater than our conservative estimate. Thus, the extent of the problems with channels 9 and 10 could be considerably different than the analysis indicated.

Experience at the two operating PAVE PAWS radars shows that the major TV interference effect has not been high-power or saturation effects or the spurious-response effect on the TV receiver. Rather, the main interference has been the saturation of antenna-mounted wide-bandwidth preamplifiers. The Air Force has developed and has made available without charge an antenna-mounted band-stop filter to be installed between the antenna and the preamplifier to prevent the strong PAVE PAWS

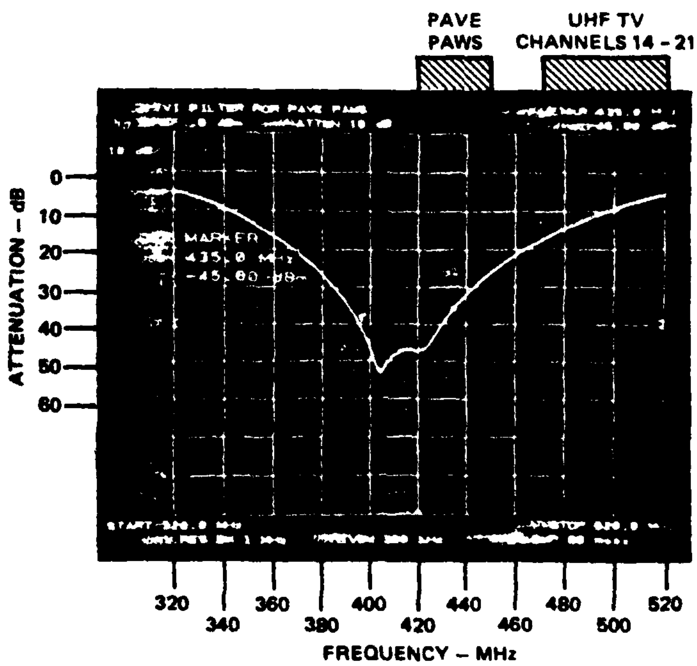
signal from entering the preamplifier. Figure C-7 shows the attenuation characteristics of one of these filters as measured in the laboratory. The top photo shows the spectrum from 0 to 1000 MHz, illustrating the portions occupied by VHF TV, PAVE PAWS, and UHF TV. The deep notch indicates the attenuation that reduces the harmful effect of the PAVE PAWS signal. The bottom photo is an enlarged view of the notch, showing only the spectrum from 320 MHz to 520 MHz. The attenuation of the PAVE PAWS signal ranges from about 47 dB to about 25 dB (a factor of about 50,000 to about 300) depending on the actual PAVE PAWS frequency. Although reception of the VHF TV channels will be improved by use of the band-stop filter to remove PAVE PAWS signals, some undesirable attenuation of TV signals will occur in the lower part of the UHF spectrum. For channel 14, the attenuation is about 18 dB; the attenuation decreases to about 4 or 5 dB as the frequency increases to about channel 21. This may seriously degrade reception of TV channels 15 and 17 near Robins AFB, but it would probably create no problem near Moody AFB, where the lowest UHF channel is channel 27. The lower photo graphically shows that the PAVE PAWS band is not at the deepest part of the notch. It is simple to trim the filter so that the notch is centered in the PAVE PAWS band, reducing the effect of the radar by another 10 dB or more. However, this would also result in increased attenuation in the UHF TV spectrum, so that a greater portion of it would be affected and to a greater degree.

To combat effects other than saturation of preamplifiers, the Electromagnetic Compatibility Analysis Center (ECAC) has experimented with simple filters to attach to the back of individual home TV receivers. Figure C-8 shows a sketch of the most simple type, a 5 3/8-in. piece of flat TV lead-in cable, connected as shown. This filter, which the Air Force had planned to provide on request at the first two PAVE PAWS radars, can reduce susceptibility by a factor of more than 100 (20 dB), which would make receiver saturation interference to even the closest receivers highly unlikely. Experiments indicate that a slightly more sophisticated filter can attenuate the PAVE PAWS signal by a factor of more than 10,000 (40 dB). This more sophisticated filter would improve the susceptibility thresholds shown on Figures C-5 and C-6 by 40 dB. Then, interference to TV receivers in the PAVE PAWS areas would be almost impossible.

Another way to alleviate the problem of potential spurious signals is to modify the operation of the radar. The potential problem for TV channel 10 at Moody AFB results from PAVE PAWS operation only in the band from 431 to 437 MHz, which includes only 6 of the 24 PAVE PAWS channels. If operational requirements permit discontinuing the use of those six PAVE PAWS channels, there would be no possibility of spurious signals on channel 10. A less radical alternative may be available, following experiments to determine which of the six PAVE PAWS channels are most disruptive to TV reception. The PAVE PAWS signal frequencies causing spurious responses near the TV picture carrier are probably a greater concern than the others. Perhaps deleting only one or two PAVE PAWS channels in the 431- to 437-MHz band (when it would not jeopardize PAVE PAWS operations) would accomplish the objective of alleviating the spurious signal problem for channel 10.



(a) THE SPECTRUM INCLUDING VHF TV, UHF TV, AND PAVE PAWS



(b) THE SPECTRUM INCLUDING PAVE PAWS AND SOME UHF TV

FIGURE C-7 ATTENUATION OF THE AIR FORCE'S TV INTERFERENCE FILTER

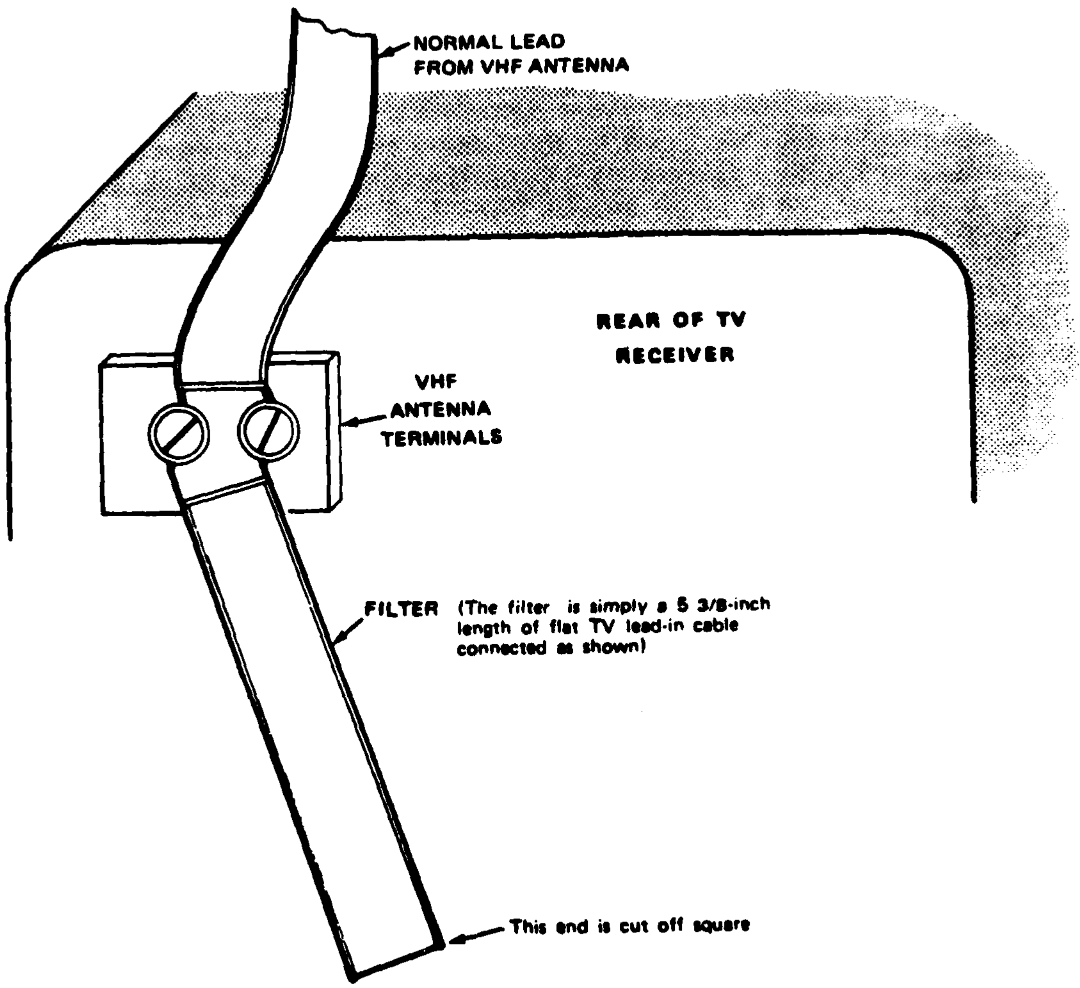


FIGURE C-8 FILTER TO EXCLUDE PAVE PAWS SIGNALS FROM TV RECEIVER

The channel 9 problem involves PAVE PAWS frequencies from 420 to 425 MHz--about 4 of the radar's 24 channels. Similarly, curtailment of operation on some or all of these channels could be considered as one means of eliminating the problem, should it occur.

C.3.1.3 Effects on UHF/FM Land Mobile Radio

C.3.1.3.1 Land Mobile Radio Usage. The bands adjacent to PAVE PAWS, both above and below, are used by UHF land mobile radio. The frequency band below PAVE PAWS (i.e., from 406 to 420 MHz) is used by agencies of the federal government, such as the Department of the Interior, the Forest Service, the Air Force, and others. It is under the control of the National Telecommunications and Information Administration. The frequency band above PAVE PAWS (i.e., from 450 to 470 MHz) is used by the nonfederal government land mobile service, which includes users such as local governments (police, fire, highway maintenance, and such services), land transportation, industry, business, and so on. That portion of the spectrum is under the control of the Federal Communications Commission (FCC).

Identical equipment (narrow-band FM voice systems) is used in both bands, as well as by the ham operators who share the PAVE PAWS band. Communication is typically between a base station and associated mobile units.

Very often, a high tower or mountaintop or rooftop repeater is used to extend the coverage area of the particular network. A repeater typically consists of a receiver and a transmitter; the receiver output is fed directly into the transmitter, operating at a frequency just 5 MHz lower. A repeater must receive and transmit simultaneously. Some repeaters have a single antenna; to keep the transmitter's signal from overwhelming the receiver, the transmitter and the receiver are connected to the antenna through a duplexer. The duplexer is an arrangement of filters that allows the weak incoming signal to pass with low loss to the receiver; simultaneously it passes the transmitter signal to the antenna to be radiated, but keeps this strong signal from reaching the receiver. Some repeaters use separate transmit and receive antennas, typically spaced vertically on the same antenna mast, and rely on the antenna patterns (and possibly also on a bandpass cavity filter with a deep notch at the transmit frequency) to protect the receiver from desensitization by the transmitter.

The repeaters are the most vulnerable part of the land mobile networks, for two reasons. First, because the repeaters are located at high elevations or use tall towers to cover a large area, some of them may be in the line of sight of PAVE PAWS. Second, because so much of the land mobile voice traffic passes through the repeaters, interference caused to the repeaters would be retransmitted to base stations and to mobile units not themselves located so as to be directly affected by the radar.

Using a computer-based retrieval system, the FCC provided a listing of the nonfederal government repeaters within 50 miles of both of the two potential PAVE PAWS locations and in the frequency range 450-470 MHz (Linthicum, 1982). Tables C-9 and C-10 show the repeaters' transmitting frequencies, call signs, and distances (to the nearest mile) from the prospective PAVE PAWS locations at Robins AFB and Moody AFB, respectively. The frequencies on which they receive are 5 MHz higher. The maps of Figures C-9 and C-10 show the locations of some of the repeaters and of the potential PAVE PAWS sites. Some favorably situated mountaintops or tall towers accommodate numerous repeaters, and some repeaters are shared by several users. The repeaters listed in the tables are keyed to the maps to show their approximate locations. Letters on the maps are generally used to represent the presence of several colocated facilities. Repeaters beyond 50 miles, even though they may be of interest, are not included in the maps or the tables.

The FCC search found 107 civilian land mobile repeaters within 50 miles of PAVE PAWS at Robins AFB and, as Figure C-9 shows, many of the closer ones are behind the radar. The nearest three repeaters are in front of the radar only about 2 miles away. Their antennas are mounted at or near the top of a 335-ft tower on a prominent point so that, as Figure C-1 indicates, they are just outside the beamwidth of the main beam (but still on the main lobe) and are frequently illuminated by the full strength of the radar's first sidelobe.

Fifty-eight FCC-licensed repeaters are located within 50 miles of the proposed PAVE PAWS site at Moody AFB. The nearest repeaters in front of the radar are about 12 miles away in Valdosta; the next nearest are about 35 miles away.

The Electromagnetic Compatibility Analysis Center (ECAC) provided records of frequency assignments in the government land mobile band for government systems operating within 30 miles of each of the two potential PAVE PAWS locations (Siemen 1982). Twenty-four systems were listed near Robins AFB and only two near Moody AFB. All but five were assigned to the Air Force, and most of those were actually at Robins AFB. The systems are used for a variety of communication purposes; they are listed by transmitting frequency in Table C-11. That table and Figures C-9 and C-10 identify most of the government land mobile systems near PAVE PAWS. (Letters and numbers relate the map and table, as was done for the civilian systems.) One system was deleted for security reasons, but its equipment type, frequency, and location are not atypical.

A typical land mobile base or repeater system will have an antenna with a gain of about G_r = 10 dBi. Loss in the feedline, L_f, will be about 1 dB. A signal level of about P_r = -117 dBm at the receiver terminals will be needed to provide a strong audio signal for the listener (or for retransmission by a repeater). RF signal levels above that level provide added protection against multipath fading, noise, and interference. A mobile unit would have an antenna with a gain of about G_m = 2 dBi and negligible loss in the feedline. The power output of a base or repeater would be about 100 to 300 W (P_t = 50 to 55 dBm), and that

Table C-9

REPEATERS IN THE CIVIL LAND MOBILE BAND WITHIN
50 MILES OF PAVE PAWS AT ROBINS AIR FORCE BASE

Transmitting Frequency (MHz)	Call Sign	Distance from PAVE PAWS (miles)	Location Key for Map
451.050	KVM815	30	1
451.050	KVM809	44	2
451.050	KVK599	35	A
451.200	KVK566	2	B
451.200	WRN462	35	5
451.200	KVK567	16	C
451.200	KVO507	16	C
451.200	WZW858	35	A
451.225	KVM660	2	B
451.225	KVM810	27	D
451.400	KTS472	14	11
451.425	KVK597	27	D
451.425	KVO490	39	E
451.425	KVO548	39	E
451.475	KVO490	39	E
451.475	KVO507	16	C
451.525	KKG543	40	17
451.625	KBG937	16	C
451.925	WYG831	29	19
452.175	WZW810	21	20
453.925	WSB714	12	21
453.975	KNBW24J	39	F
460.250	KVF524	19	G
460.325	WZB447	18	H
460.450	WZB447	18	H
460.500	WZB447	18	H
461.075	KQD529	17	I
461.075	WXD978	17	I
461.075	WXS767	17	I
461.075	WYS342	17	I
461.075	WYZ842	17	I
461.075	WZL812	17	I
461.100	WQQ741	18	33
461.125	KNBI56L	21	J
461.125	KSH364	21	J
461.175	KIV568	45	K
461.175	WYB332	45	K
461.175	WZC204	45	K
461.225	WRX577	48	39
461.275	KNAV34H	32	L

Table C-9 (Continued)

Transmitting Frequency (MHz)	Call Sign	Distance from PAVE PAWS (miles)	Location Key for Map
461.275	WSI858	32	L
461.350	KUC300	14	42
461.425	WYV588	21	M
461.425	KTZ891	21	M
461.450	KOI478	18	H
461.500	WZG478	33	46
461.600	KAH620	17	N
461.600	KBT824	17	N
461.600	KFL476	17	N
461.800	KIV783	17	O
461.950	WRC927	45	K
461.950	WYK764	45	K
461.950	WYP574	45	K
461.950	WZR531	45	K
461.950	WZR637	45	K
462.125	WYY539	48	L
462.125	KXU842	48	L
462.125	KZO932	48	L
462.125	WYT927	48	L
462.125	WYU329	48	L
462.125	WYT928	48	L
462.150	WQI435	17	N
462.150	WRB911	17	N
462.150	WRX987	36	64
462.150	WYD522	17	N
462.250	WRX491	36	P
462.450	WRX490	36	P
462.475	KIX925	21	68
463.375	WRK341	20	Q
463.375	WRC871	20	Q
463.375	WRZ398	20	Q
463.650	KAP772	17	O
463.725	KQU616	3	R
463.725	KSJ843	3	R
463.725	WYD472	3	R
463.800	WRR865	38	77
463.925	KKF841	39	S
463.925	WQK217	39	S
463.925	WXF312	39	S
463.925	WXF489	39	81
463.950	KBE779	17	N
463.950	KLH498	17	N
463.950	KRT531	17	N

Table C-9 (Concluded)

Transmitting Frequency (MHz)	Call Sign	Distance from PAVE PAWS (miles)	Location Key for Map
463.950	KVL405	17	N
463.950	KZY395	17	N
463.950	WYA606	17	N
464.025	KGG708	39	E
464.025	KJZ510	38	F
464.025	WRB910	38	F
464.025	WYJ625	38	F
464.225	KEH795	21	T
464.225	KGA209	19	U
464.225	KOI760	21	T
464.225	KQA756	21	T
464.225	WRB923	21	T
464.225	WXX335	21	T
464.225	WYS341	21	T
464.225	WYS343	21	T
464.225	WYT740	21	T
464.225	WZF834	21	T
464.225	WZY918	21	T
464.400	KD0837	19	U
464.825	KGF285	10	104
464.950	KTT794	21	T
464.975	WYB944	26	106
465.025	WZU328	19	G

Table C-10

REPEATERS IN THE CIVIL LAND MOBILE BAND WITHIN
50 MILES OF PAVE PAWS AT MOODY AIR FORCE BASE

Transmitting Frequency (MHz)	Call Sign	Distance from PAVE PAWS (miles)	Location Key for Map
451.100	KAB742	43	1
451.100	KAB743	40	2
451.100	KAB738	42	3
451.400	KUO736	10	4
451.425	KZX739	17	5
451.425	KDF612	34	6
451.525	KDF618	27	7
451.700	KLR901	46	8
451.700	KSK900	36	9
461.125	KOH994	43	A
461.125	KZK960	43	A
461.125	WXH352	43	A
461.125	WXU989	43	A
461.125	WYS866	43	A
461.225	WRX576	18	B
461.275	WYT274	24	16
461.300	WYY760	18	B
461.300	KXK822	18	B
461.675	KTI728	13	C
461.675	WRE994	13	C
461.675	WRG250	13	C
461.675	WSB984	13	C
461.675	WXC238	13	C
461.675	WYF758	13	C
461.800	WRN366	43	D
463.275	KIF534	44	D
463.275	KIS623	44	D
463.325	KUN517	48	E
463.325	KKB745	48	E
463.325	KWA935	48	E
463.325	WXA673	48	E
463.325	WYD539	48	E
463.325	WYX275	48	E
463.325	WZK295	48	E
463.325	WYH904	48	E
463.350	KAM523	39	F
463.925	KMD948	39	F
463.925	KQD883	39	F
463.925	WYD734	39	F
463.925	WYE482	39	F

Table C-10 (Concluded)

Transmitting Frequency (MHz)	Call Sign	Distance from PAVE PAWS (miles)	Location Key for Map
463.975	WRI688	36	G
463.975	WSA264	36	G
463.975	WSZ964	36	G
464.200	KOG515	11	H
464.200	WYU646	11	H
464.200	WYX276	11	H
464.275	KRX803	12	I
464.275	WXA694	12	I
464.300	KKI875	39	F
464.300	KKX668	39	F
464.300	KQE339	39	F
464.300	KYN555	39	F
464.300	WXL982	39	F
464.300	WZS254	39	F
464.800	KMD923	12	I
464.800	KOI240	12	I
464.800	KOP344	12	I
464.800	WXB310	12	I

SCALE

0 10 20 30 40

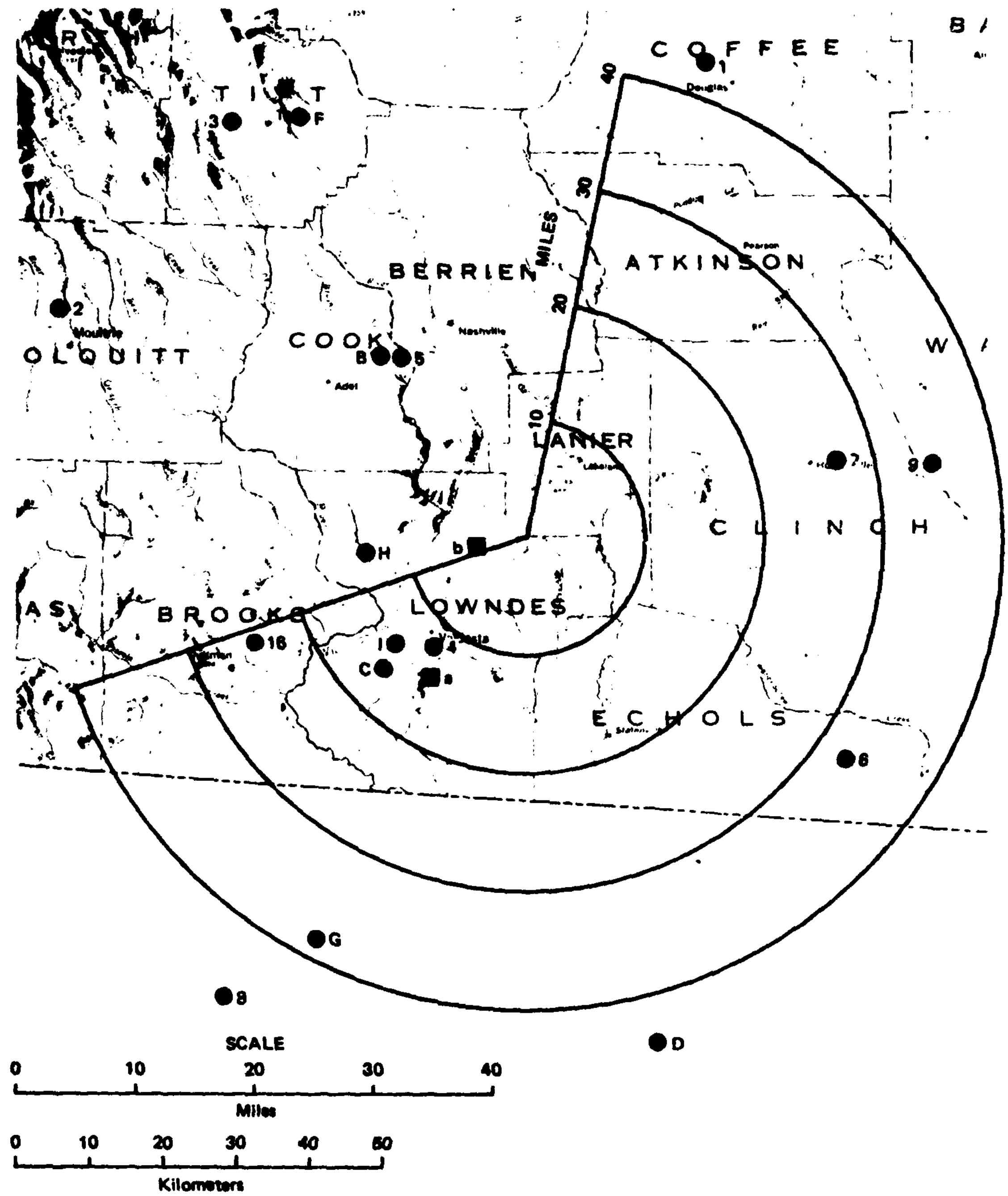
Miles

0 10 20 30 40 50

Kilometers

NOTE: Numbers and letters are keyed to Tables C-8 and C-11. Letters are used to represent several collocated facilities.

FIGURE C-9 LAND MOBILE REPEATER LOCATIONS WITHIN 50 MILES OF PAVE PAWS AT ROBINS AFB



NOTE: Numbers and letters are keyed to Tables C-10 and C-11. Letters are used to represent several collocated facilities.

FIGURE C-10 LAND MOBILE REPEATER LOCATIONS WITHIN 50 MILES OF PAVE PAWS AT MOODY AFB

Table C-11

FREQUENCY ASSIGNMENTS IN THE GOVERNMENT UHF LAND MOBILE BAND FOR LOCATIONS WITHIN 30 MILES OF PAVE PAWS

Frequency (MHz)	Agency	Location Key for Maps
Robins AFB		
407.375	USAF	A
407.400	USAF	B
407.400	USAF	C
407.450	USAF	A
407.475	USAF	A
407.550	USAF	B
407.550	USAF	C
407.575	USAF	B
407.575	USAF	C
412.975	USAF	A
413.025	USAF	A
413.100	USAF	B
413.125	USAF	A
413.150	USAF	14
413.200	USAF	B
413.275	USAF	A
413.300	USAF	B
413.400	USAF	B
413.425	USAF	A
413.450	USAF	B
413.950	GSA	D
415.200	GSA	D
451.050	FCC	23
451.050	FCC	24
Moody AFB		
408.825	FAA	a
413.150	USAF	b

Abbreviations: FAA - Federal Aviation Administration
FCC - Federal Communications Commission
GSA - General Services Administration
USAF - United States Air Force

of the mobile unit would typically be about 25 to 50 W (P_t = 44 to 47 dBm).

Optimistically assuming a line-of-sight path from a mobile unit to a repeater or base station d miles away, the level of the mobile unit's signal at the terminals of the receiver would be about

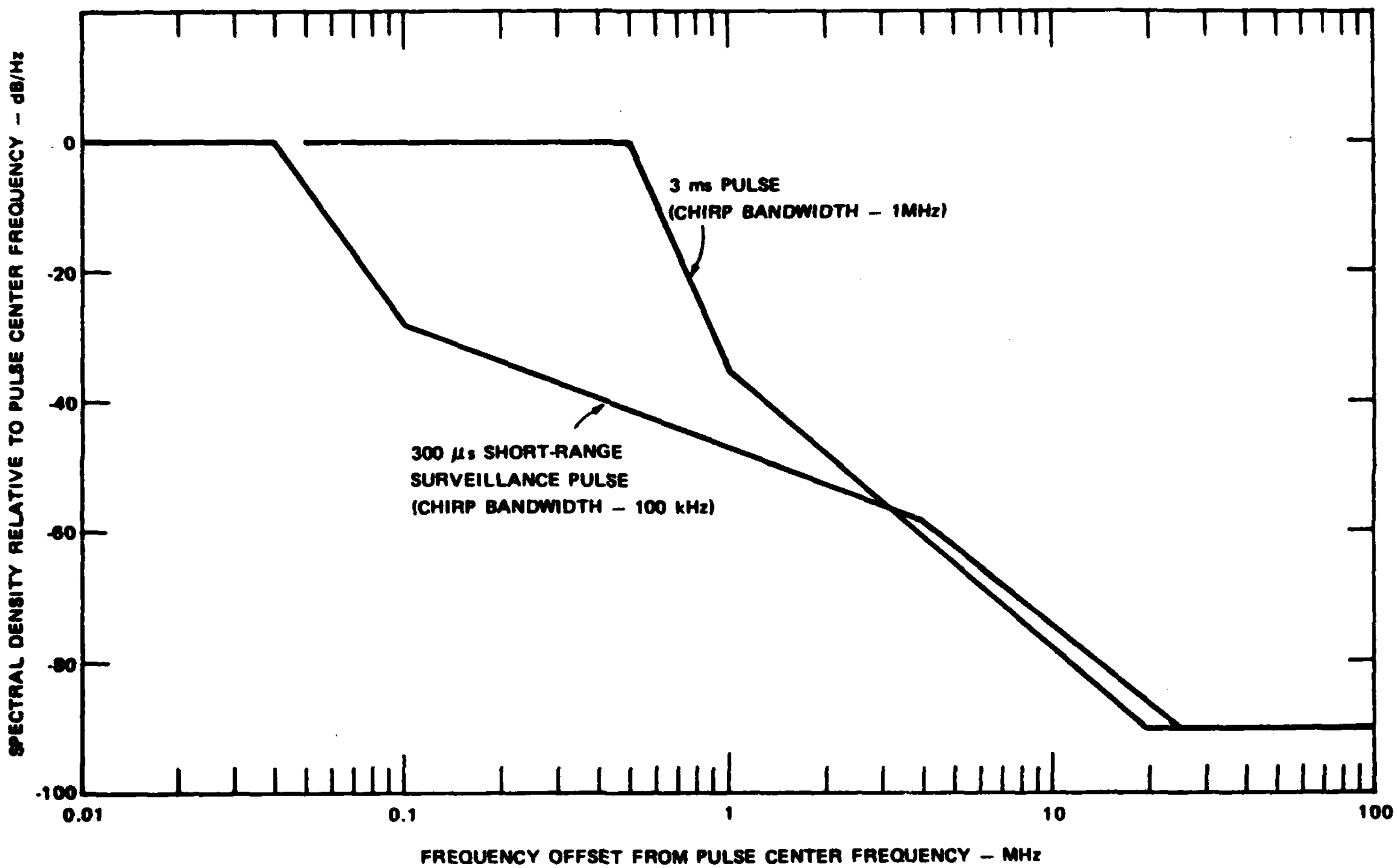
$$P_r = P_t + G_r + G_m - L_f - 89 - 20 \log d_{miles} \quad \text{dBm} \quad .$$

Using the antenna gains mentioned in the preceding paragraphs and a 44-dBm mobile unit about 40 miles from the repeater, the power will be about P_r = -66 dBm, far above the minimum signal necessary for the system. Different assumptions would affect this optimistically estimated level considerably; but if the distance were halved (or doubled), the level would increase (or decrease) by only 6 dB. However, the signal level would be much lower without a clear line-of-sight path. One factor that will greatly affect the level of the received signal is the amount and thickness of the foliage that must be traversed by the signal. Thick forest will greatly attenuate the land mobile (and the PAVE PAWS) signal.

C.3.1.3.2 PAVE PAWS Signals at the Land Mobile Receivers. Because the land mobile systems operate both above and below the band used by PAVE PAWS, the power that PAVE PAWS spreads outside its own band and into theirs is of interest. Figure C-11 shows estimates of emission-spectrum upper bounds for the most common pulse emitted by PAVE PAWS--the 300-microsecond, chirped, short-range-surveillance pulse--and also for a 3-ms chirped pulse. The latter pulse is not actually in the PAVE PAWS pulse repertoire, but it was used in some analysis by Beran (1978) and is similar to one used in experimental work by Hurt and Sigurst (1978). The bandwidth of a land mobile receiver (about 15 kHz) is narrow with respect to these emission spectra, so that it could not accept all of the PAVE PAWS power even if there were no frequency offset. For the 300-microsecond pulse, we use a power reduction factor, R, of about 16 dB, based on the pulse's bandwidth and the receiver's bandwidth (Duff and White, pp. 2.27, 1972). Therefore, the PAVE PAWS power in the bandwidth of the land mobile receiver, relative to that in a similar bandwidth at the actual PAVE PAWS frequency, is determined principally by the levels of the emission spectrum at the two frequencies. For example, at a frequency offset of 10 MHz between the land mobile system and the pulse center frequency, the receiver will be subject to about 75 dB less PAVE PAWS power than if there were no offset. This is called frequency-dependent rejection (FDR), and we can estimate the PAVE PAWS signal power at a receiver that is in the line of sight of the radar by

$$P_r = P_p + G_r + G_p - L_f - 89 - 20 \log d_{miles} - R - FDR \quad \text{dBm}$$

where P_p and G_p are the PAVE PAWS power (P_p = 92.4 dBm) and antenna gain. The second sidelobe and the higher order sidelobes will illuminate most systems in the vicinity of PAVE PAWS, with gains of 24.1 dBi and 13.1 dBi, respectively. (The Georgia Power Co. repeaters only 2 miles



SOURCE: Beran (1978)

FIGURE C-11 RELATIVE SPECTRAL DENSITY BOUNDS OF PAVE PAWS PULSE

from the Robins AFB PAVE PAWS are exceptions.) Assuming the same base station (or repeater) as before, and that no attenuation by foliage exists, the PAVE PAWS power at the receiver will be no greater than

$$P_r = 20.5 - 20 \log d_{miles} - FDR \quad dBm$$

for the second sidelobe and about

$$P_r = 9.5 - 20 \log d_{miles} - FDR \quad dBm$$

for the higher order sidelobes.

To estimate the PAVE PAWS signal power at each repeater, it would be necessary to determine the frequency and the elevation of each and to examine the terrain between each and the PAVE PAWS radar. Instead, since we know that many are on tall towers, we assume, as a worst case, that they have a line-of-sight path to PAVE PAWS. (A 300-ft tower at about 25 miles would have such a line-of-sight path unless there were intervening hills.) The distance attenuation term (20 log d) for such a path is only about 28 dB, so that the PAVE PAWS signal level at a distance of 25 miles could be as great as

$$P_r = -7.5 - FDR \quad dBm$$

for the second sidelobe, and about

$$P_r = -18.5 - FDR \quad dBm$$

for the higher order sidelobes. (Again, halving or doubling the distance amounts to only a 6-dB change.) The FDR term, of course, is a function of the frequency offset between a particular receiver and a particular PAVE PAWS pulse; it varies widely as PAVE PAWS hops among its 24 frequency channels.

C.3.1.3.3 Effects of the PAVE PAWS Signal

C.3.1.3.3.1 General. Even at the maximum estimated FDR (90 dB for a frequency offset greater than about 20 MHz), and considering the higher order sidelobes, the PAVE PAWS signals are expected to be considerably stronger than the typical land mobile system threshold of about -117 dBm. (This rough approximation considers all local land mobile systems as a class; it would be more precise if specific individual systems were considered.)

To the land mobile receiver, the PAVE PAWS pulses would all be on-frequency pulses, which could not be excluded by filtering. In general, though, the pulses affect a receiver only when it is also receiving a desired signal. The receivers have a squelch circuit that cuts off the audio system in the absence of a desired signal. Hurt and Sigurst (1978) state that a signal must be present continuously for 10 ms or more for the squelch to operate. This is the FM receiver's attack time--the time required to produce an audio signal after application of an acceptable

RF signal. (The attack time varied from 10 to 78 ms among four different units tested by Hurt and Sighurst.) Similar circuitry is used in repeaters, so that received pulses are not sent to the transmitter portion for retransmission. If the squelch were to open, the transmitter would transmit noise for an appreciable fraction of a second; squelch break at an ordinary receiver would give the listener a similar, short burst of noise. One type of PAVE PAWS tracking pulse is 16 ms long, and higher order sidelobe energy from this pulse might cause squelch break in some receivers. However, SEPP is intended to do very little tracking, so that this pulse would almost never be used. Shorter pulses would not be likely to break squelch and so would produce no effect.

When the receiver's audio system is being kept "on" by a desired signal, those pulses that are stronger than the desired signal will be heard, although it was not clear from the Hurt and Sigurst laboratory testing how they would affect efforts to communicate. Presumably, the PAVE PAWS pulses would sometimes be heard in a receiver (or be retransmitted by a repeater) if the receiver's squelch circuit is already held open by a desired signal. A characteristic of an FM receiver is that the receiver is "captured" by the strongest of the signals in its passband. If a potentially interfering signal is weaker than the desired signal, it will not cause perceptible interference; however, if the potentially interfering signal is the stronger, then it will capture the receiver. Momentary capture of an FM receiver by a pulse would probably result in the listener hearing a pop or a click for each pulse that exceeded the level of the desired signal. However, if the pulses occur infrequently enough and are brief enough, they may never be noticed.

The "PRF" (see Section C.2.2) for the energy-spreading second-sidelobe short-range surveillance pulse on a given PAVE PAWS channel is only about 1.2 pps. (This number could change slightly during the final radar design.) Because of the frequency spreading of the PAVE PAWS pulses, the land mobile channels closer to the PAVE PAWS band could be affected by more of the PAVE PAWS channels. The number of PAVE PAWS channels that might cause effects decreases as the frequency offset increases. The civilian and the federal government bands would each be affected in the same way. Interfering pulses at a low "PRF" would not be likely to cause serious loss in the ability to pass voice-modulated information over a land mobile channel.

Similar analysis could be done for mobile units. However, a mobile unit operating through a repeater illuminated by PAVE PAWS would receive the PAVE PAWS signal regardless of its own location relative to the radar. The previous conclusions regarding the inability of PAVE PAWS to open the squelch apply also to the mobile units. Thus, the only unique concern is how the mobile receiver would be affected when receiving from a base station without benefit of a repeater. The level of the desired signal at the mobile unit would be similar to that at a base or repeater. Because propagation between PAVE PAWS and the mobile unit would often not be line of sight, the PAVE PAWS signal strength could be considerably less at a mobile unit than at an elevated antenna at the same distance. Assuming that the mobile receiver were located close enough so that the

PAVE PAWS signal always exceeded the desired signal, the results would be as described for land mobile channels at frequencies essentially adjacent to PAVE PAWS (i.e., there would be several pops every second). Again, the low "PRFs" and short pulse lengths would not be expected to cause serious disruption to voice communications. Thus, considering the low pulse rates and the short pulse lengths involved, it is unlikely that PAVE PAWS would significantly affect the ability of most land mobile systems to convey information by voice, and might never be noticed.

This seems to have been confirmed by practical experience in the vicinity of PAVE PAWS at Beale AFB in California. Although some had expressed concern in 1979 about serious interference to repeaters that were in line of sight of PAVE PAWS, this interference has never been noted on most local land mobile systems and has never been detrimental. Discussions with a principal officer of Colusa Communications, which operates more than 20 repeaters in direct sight in front of PAVE PAWS, confirmed that they have experienced no interference from PAVE PAWS (Fitch, 1982). Similarly, a supplier of land mobile radio systems, who had been extremely concerned about the potential of interference, has closely monitored the situation and notes that no harmful effects have occurred (Olson, 1982).

C.3.1.3.3.2 The Georgia Power Company Repeaters. The Georgia Power Company operates three UHF transmitters (as well as a 6-GHz microwave system) on a 335-ft tower about 2 miles from and in front of PAVE PAWS at Robins AFB (see Figure C-1). Depending on the antenna heights on the tower, the antennas may be illuminated by a portion of the main beam in the surveillance mode. They will certainly be illuminated from time to time by the first sidelobe, as well as by all of the other sidelobes. Thus, considering only the first sidelobes, their power at the land mobile receivers, due to the radar's out-of-band emission spectrum, will be approximately P_r = 14.5 - FDR dBm.

The transmitting frequencies are 451.200 MHz, 451.225 MHz, and 451.475 MHz. (The FCC listing indicates that only the first two of these are repeaters; the third may be a remote transmitter for a simulcast system.) The receiving frequencies for the repeaters are 5 MHz higher than the transmitting frequencies. They are offset from the highest PAVE PAWS channel by only about 7 MHz and from the lowest PAVE PAWS channel by about 35 MHz, so that the FDR term ranges between approximately 70 dB and 90 dB, and the received PAVE PAWS power from the out-of-band emission spectrum will range between about -55 dBm and -75 dBm. Such power levels would generally be sufficient to cause interference to the repeaters.

Yet another potential interference mechanism exists for land mobile systems so close to the radar. Their front-end bandwidths may be so wide that they accept sufficient PAVE PAWS energy (even though it is not at the land mobile operations frequency) to saturate their first stage. Although we do not know how much the duplexers or other filters of the repeater systems would attenuate the PAVE PAWS signal, the fundamental

power of the PAVE PAWS may be sufficient to saturate the relatively wide front ends of the receivers and cause serious desensitization. Even if filtering could prevent this saturation effect, the portion of the energy in the radar's out-of-band emission spectrum that falls directly into the receiver passband would still generally be sufficient to interfere with the receivers.

These Georgia Power Company systems, unlike all the other land mobile systems near the two proposed PAVE PAWS sites, are likely to suffer some amount of interference. However, because of the wide variation in the frequency, timing, and strength of the PAVE PAWS signals that will reach the receivers, it is not feasible to produce a quantitative prediction of the degree, or seriousness, of the interference that will occur.

C.3.1.3.4 Summary of UHF Land Mobile Susceptibility. Although the PAVE PAWS pulses will certainly appear at the input terminals of any land mobile receiver within the line of sight of the radar, they are not generally expected to cause serious disruption to voice communication. PAVE PAWS pulses are generally not long enough to open the squelch circuit of the receivers; therefore, they would not cause any perceptible effect to a receiver that is not already receiving a desired signal. Although the pulses will be strong, they will be very brief; moreover, they will occur at such low pulse rates that conversation should be possible despite an occasional pop or click.

The probable exception to the above statements is the Georgia Power Company system closely in front of the PAVE PAWS radar at Robins AFB. Interference is likely there.

C.3.1.4 High-Power Effects to Electronic Systems

High-power interference to the operation of an electronic system results from the direct coupling of the interfering signal to internal circuits and components via the equipment case, antenna leads, power line, or signal leads. The meager data available suggest that high-power effects will probably be a problem with some home phonographs, radios, and televisions at distances as far as Valdosta in front of a Moody AFB PAVE PAWS or as far as the southern parts of Warner Robins behind a Robins AFB PAVE PAWS. Donaldson (1978) describes high-power effects as being "significantly different from the classical, frequency dependent EMI problems (co-channel interference, spurious responses, intermodulation, etc.)." The systems potentially subject to interference can be classified as either civilian or military.

C.3.1.4.1 Civilian Systems. Moss (1978) has stated, as a summary of some work done previously for the Air Force, that high-power interference "can occur in civilian electronics equipment when the peak power density is in excess of 30 dBm/m^2" ($0.1\ mW/cm^2$). Siemen (1978) used the same number. However, the situation is not really so clear-cut that a single susceptibility level can be applied to all such electronic equipment.

Donaldson (1978) sampled 20 solid-state home stereo systems, each consisting of an AM/FM-stereo receiver, a tuner, an amplifier, a record changer, and speakers. Four major manufacturers were represented. The units covered a wide cost range and differed widely in chassis configuration. Donaldson's tests were in the frequency range from 400 to 450 MHz, but he did not present any further details of the interference source. He found wide variations from unit to unit in thresholds for minimum perceptible interference. For all operating modes (FM/FM-stereo, AM, phonograph, or tape), the average threshold was about 7 dBm/m^2 (0.0005 mW/cm^2). Susceptibility varied widely (by a factor of 100, i.e., by 20 dB) with orientation and was also affected by the level of the desired signal.

A transistor AM receiver was measured. At approximately 450 MHz, thresholds were about 22 to 32 dBm/m^2 (0.016 to 0.16 mW/cm^2). Varying the pulse width and PRF had little effect on the thresholds.

Tests were also made on one solid-state AM/FM broadcast receiver. A threshold of about 20 dBm/m^2 (0.01 mW/cm^2) was noted at about 450 MHz for the pulse width and PRF used. We estimated that the threshold might be about the same at a pulse width of about 300 microseconds and a PRF of about 70 pps. (Those are the most common PAVE PAWS pulse width and a typical PAVE PAWS "PRF.")

In addition, three "inexpensive phonographs and a tape recorder" were tested using a PRF of 40 pps with pulse widths of 0.2 ms, 1.0 ms, and 6.0 ms. At the 0.2-ms pulse width, the susceptibility thresholds ranged from 1 to 6 dBm/m^2 (0.00013 to 0.0004 mW/cm^2).

Susceptibility of 16 hearing aids ranged from about -17 to +38 dBm/m^2, with a median of about 16 dBm/m^2 (0.000002 to 0.63 mW/cm^2, with a median of 0.004 mW/cm^2).

Tests were also conducted on one UHF land mobile transceiver (without its antenna connected) operating in the 450- to 470-MHz band. The threshold of high-power susceptibility for the radar characteristics used was about 42 dBm/m^2 (1.6 mW/cm^2). The threshold for susceptibility to PAVE PAWS would probably be about 35 dBm/m^2 (0.32 mW/cm^2).

Two VHF FM land mobile transceivers were tested. They were different solid-state models by the same manufacturer that operate in the 136- to 174-MHz range. Tests were made to determine not only the threshold of interference with the desired signal, but also whether the interfering signal could be made to break squelch. When the transceivers were receiving, the thresholds were 16 and 25 dBm/m^2 (0.004 and 0.032 mW/cm^2) for the two units. When the equipment was not receiving, the interfering signal could not break squelch at levels up to the maximum available power density of 37 dBm/m^2 (0.5 mW/cm^2). In this instance, curves that would permit an extrapolation of the data to the pulse width and "PRF" of PAVE PAWS were not provided.

A single high-fidelity tape recorder was tested at various frequencies, PRFs, and pulse widths. At the pulse width and PRF applicable to the PAVE PAWS signal, the unit's susceptibility threshold for the PAVE PAWS signal was judged to be about 14 dBm/m^2 (0.0025 mW/cm^2).

High-power effects on television were discussed in Section C.3.1.2.2.3.

C.3.1.4.2 Military Communications Systems. Moss (1978) states that the threshold criterion for military electronics is 40 dBm/m^2 (1 mW/cm^2). Tests were made on two military ground-based receivers, an AN/GRR-23 and an AN/GRR-24; both are solid-state, single-channel HF/VHF-AM receivers. The interfering signal pulse width was 80 microseconds and the PRF was 1,250 pps. Susceptibility thresholds for high-power effects were greater than 42 dBm/m^2 (1.6 mW/cm^2), and a spurious response was found in the AN/GRR-23 for an interfering frequency of 439.3 MHz at 41 dBm/m^2 (1.3 mW/cm^2).

One VHF/FM mobile unit, the receiver portion RT-246/VRC of an AN/VRC-12, was also measured. No high-power effects were noted at approximately 430 MHz at field levels as high as almost 40 dBm/m^2 (1 mW/cm^2).

C.3.1.4.3 Susceptibility to PAVE PAWS. The sparse information on the susceptibility of electronic systems to high-power effects is summarized in Table C-12. All of the systems described in this analysis are ground-based systems that could be exposed, in the worst possible case, to the second sidelobe in the 240-deg sector in front of the radar. Behind the radar, there would be exposure to scattered and diffracted energy at a much lower level. Figure C-12 shows how the power density from those two sources decreases with distance. Both curves have been adjusted downward by a very conservative 10 dB to account for the attenuation of the PAVE PAWS signal by the trees that stand between the radar and any other buildings at either proposed radar site.

Figure C-12 also indicates the ranges of thresholds of susceptibility for the military and civilian systems listed in Table C-12. Power density levels corresponding to some of the susceptibility thresholds of Table C-12 may occur behind a radar site at distances less than about 3 miles; at Robins AFB this includes base housing and parts of the city of Warner Robins. Similar levels may be reached in front of a PAVE PAWS radar at distances greater than about 20 miles; at Moody AFB this includes the city of Valdosta. As an example, the average threshold of susceptibility of 20 home stereo systems was about 7 dBm/m^2 (0.0005 mW/cm^2); this level may be reached within about 18 miles in front of or about 2 miles behind the radar. Shielding by terrain and increased losses through vegetation and home structures may make the effects less widespread. However, better definition of the extent of the potential problem cannot be made, for two reasons. First, the susceptibility testing that has been done did not use the pulse-width and "PRF " applicable to PAVE PAWS; thresholds are dependent not only on frequency, but also on pulse width and PRF. Second, only a very small sample of

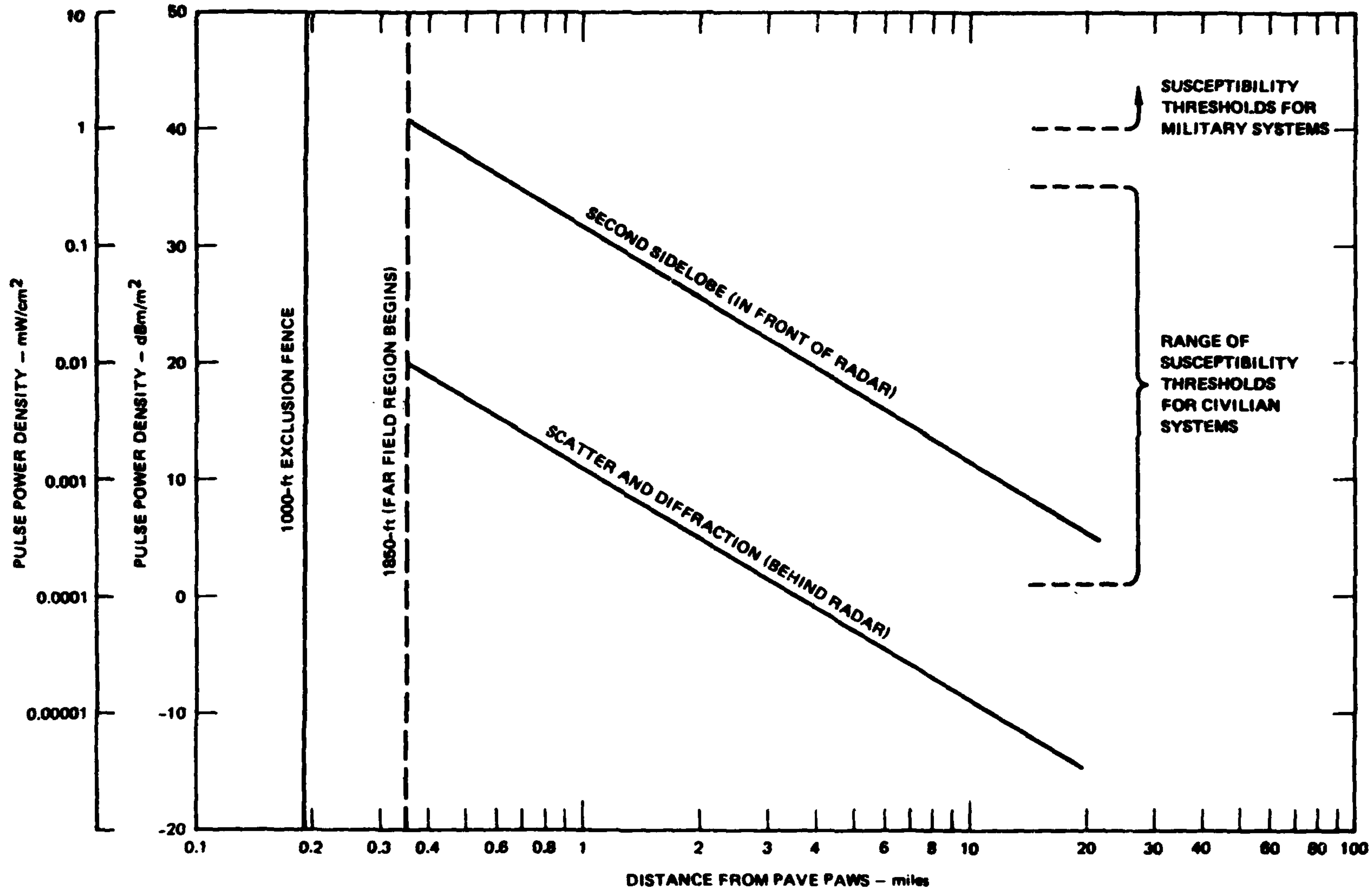


FIGURE C-12 HIGH POWER EFFECTS FOR VARIOUS ELECTRONIC SYSTEMS

Table C-12

SUMMARY OF SUSCEPTIBILITY THRESHOLDS
FOR HIGH-POWER EFFECTS

System Type	Units Tested	Threshold dBm/m^2	Threshold mW/cm^2
Civilian			
AM/FM receivers, record changer, etc.	20	7 (average)	0.0005
AM receiver	1	22-32	0.016-0.16
AM/FM receiver	1	20 (approx.)	0.01
"Inexpensive" phonograph	3	1-6 (range)	0.00013-0.0004
Hearing aids	16	16 (median)	0.004
UHF FM land mobile receiver	1	35 (approx.)	0.32
VHF FM land mobile receiver	2	16 and 25	0.004 and 0.032
Hi-fi tape system	1	14	0.0025
Military			
HF/VHF AM receiver	2	greater than 42	greater than 1.6
Mobile FM receiver	1	greater than 40	greater than 1.0

electronic units has been tested; their responses are not necessarily representative of those of all systems that will be exposed. It is worth noting that there has not been a great number of complaints of interference from the West Coast PAVE PAWS, where the cities of Marysville and Yuba City are in front of the radar at a distance of 12 or 13 miles and totally without the benefit of any thick trees for shielding.

C.3.1.5 Airborne Systems

C.3.1.5.1 In-Band Radar Altimeters. Two aircraft radar altimeters--the SCR-718 and the AN/APN-1--share the 420- to 450-MHz band with PAVE PAWS and other radar systems. That the altimeters can experience interference from in-band ground-based radars is well known. Dates for the retirement of these altimeters have been set, and extended, by the Office of Telecommunications Policy, which has been succeeded by the National Telecommunications and Information Agency; but the altimeters are still in use. The most recent extension is to January 1985. Neither altimeter is used for landing approaches, and Tech Order 1C-135A-1 states that the SCR-718 is not to be used within 50 miles of land. At Robins AFB PAVE PAWS would be about 160 miles inland from the nearest part of the Atlantic; Moody PAVE PAWS would be about 80 miles inland from the nearest

part of the Gulf of Mexico. Therefore, the SCR-718 would not be used closer than about 130 to 210 miles from PAVE PAWS, depending on which base is eventually selected. The usage restrictions greatly reduce the likelihood of PAVE PAWS interference causing a hazardous situation.

The SCR-718 altimeter will generally be affected by PAVE PAWS when its aircraft is within radio line of sight of PAVE PAWS. The line-of-sight limit depends on the aircraft's altitude and the intervening terrain. For example, aircraft over the sea 210 miles from Robins AFB and below about 20,000 ft would not be illuminated by the PAVE PAWS signal (even considering refraction of the radar signal to permit it to travel farther than the geometry would indicate). For the Moody AFB site, the nearest aircraft using the altimeter would not be illuminated at altitudes below about 7,200 ft. At 250 miles, aircraft below about 30,000 ft would not be illuminated. An SCR-718 altimeter may still be able to provide useful information despite some interference by PAVE PAWS; experiments would confirm or refute this. Because radar interference to this altimeter is already acknowledged to occur, operation of PAVE PAWS would not pose a unique threat.

The AN/APN-1 altimeter will be affected by PAVE PAWS when the PAVE PAWS signals are about the same order of magnitude as the altimeter's ground return (Siemen, 1977). However, because this altimeter's power output and antenna characteristics were not listed, the area in which it would be affected cannot be defined. Moreover, its maximum useful altitude is 4,000 ft, and at that altitude or below, it would be beyond the unobstructed radio horizon for PAVE PAWS (and therefore would be unaffected) at about 100 miles. Anywhere over the ocean, and up to the maximum 4,000-ft altitude, the earth's curvature will shield aircraft using the AN/APN-1 altimeter. Again, because this altimeter already operates in the same band as other radars and is not used to determine altitude during landing approaches, PAVE PAWS should be no additional hazard to its use.

The general characteristics of the two altimeters are shown in Table C-13. The SCR-718 type is used in some C-97, C-118, C-121, C-130, C-131, and C-135 aircraft; the AN/APN-1 type is used in some A-3, C-117, C-118, C-119, and P-2 aircraft.

C.3.1.5.1.1 The SCR-718 Pulse Radar Altimeter. The operating frequency for the SCR-718 is 440 MHz, and the transmitter power depends on the altitude range in use (see Table C-13). Calculations show that it is impossible to provide enough physical separation between the altimeter and PAVE PAWS to attenuate the PAVE PAWS signal to levels that will not affect the SCR-718. It appears that the only way for the SCR-718 altimeter to be unaffected by PAVE PAWS is to be used beyond the radar's horizon.

Generally, when in radio line of sight of PAVE PAWS, an aircraft would be exposed to PAVE PAWS higher order sidelobes. Since the duration of such exposure is determined by the SEPP duty cycle, the aircraft would be illuminated for about 15% of the time. However, because of PAVE PAWS'

Table C-13

CHARACTERISTICS OF TWO RADAR ALTIMETERS

Nomenclature	SCR-718		AN/APN-1	
Frequency	440 MHz		Varies sinusoidally, 120-Hz rate	
Emission type	Pulse (0.3 microseconds)		FM-CW	
Altitude range (ft)	0-5,000	0-50,000	0-400	0-4,000
Pulse power (dBm)	38.5	37	not given	
PRF (pps)	98,350	9,835	not applicable	
Frequency range (MHz)	not applicable		420-460	443-447
Sensitivity threshold (dBm)	-70	-70	-87	-87

Source: Siemen (1977).

frequency hopping, the SCR-718 would not be susceptible to all PAVE PAWS pulses. Its receiver response curve suggests that it would be susceptible to only a few of the PAVE PAWS frequencies. A pessimistic estimate is that the SCR-718 would be affected as much as 8% of the time. Whether this would adversely affect the function of the altimeter would have to be determined, probably by experimentation.

An SCR-718 illuminated by a strong PAVE PAWS signal may still be usable. The display on the SCR-718 radar altimeter is a cathode ray tube (CRT) on which a spot continually moves in a circle. The spot takes about 10 microseconds for a revolution when the altimeter is in the low-altitude range and about 100 microseconds when it is in the high-altitude range. The return pulse causes the trace to deflect radially outward, placing a bump on the circle. Numbers superimposed on the CRT face allow the placement of the bump to be interpreted as aircraft altitude. The angle covered by the bump is dictated by the duration of the received signal (the transmitted pulse is 0.3 microseconds long, so the bump is small). Reception of a longer pulse, such as a PAVE PAWS long-range surveillance pulse (8 or 5 ms), would cause deflection of the entire circular trace for many revolutions of the spot. The persistence of the CRT face may permit the desired trace to

be seen when it occurs, despite the whole-circle deflection occurring occasionally. Experiments would have to be performed to determine whether this is so.

C.3.1.5.1.2 The AN/APN-1 FM-CW Radar Altimeter. This FM-CW altimeter transmits continually, varying its frequency in a sinusoidal manner (at a 120-Hz rate) between the frequency limits shown in Table C-13. The frequency of the signal returned from the ground is the frequency that was being transmitted a short while before, because the radar is continually changing frequency during the signal's round trip from plane to ground to plane. The radar mixes the return signal with the frequency being transmitted. The difference frequency is then amplified in an audio-frequency amplifier and limited to obtain square waves at the difference frequency. The square waves are converted to a dc voltage proportional to their frequency and thus proportional to the altitude of the aircraft.

A strong interfering signal (such as one from PAVE PAWS) can enter the receiver to mix with the frequency being transmitted and, if their frequency difference is within the passband of the audio amplifier, the square waves from that frequency will be converted to a dc value to drive the altimeter's meter. If the interfering frequency is present long enough, the meter response will be determined totally by the interfering frequency. If the interfering frequency is present only for a short while, the meter will simply read inaccurately.

In the low-altitude range, the frequency of the AN/APN-1 altimeter swings between 420 and 460 MHz; in the high-altitude range it swings between 443 and 447 MHz. Therefore, the frequency is likely to swing through a PAVE PAWS signal, which would cause interference. In the high-altitude range, the altimeter would be susceptible to interference only from the PAVE PAWS signals inside (approximately) the 443- to 447-MHz band, and so only 5 of the 24 PAVE PAWS frequencies seem likely to pose any problem at high altitudes. In the low-altitude range, the altimeter would be susceptible to all 24 PAVE PAWS frequencies, but the altimeter's 40-MHz frequency swing also takes it 10 MHz above the PAVE PAWS band. Because the altimeter operates outside the PAVE PAWS band for 25% of the time, only the other 75% is of concern to PAVE PAWS. However, in the 25% of the time the altimeter operates above the PAVE PAWS band, it may be susceptible to interference from land mobile radio, which operates in that frequency range.

Interference from PAVE PAWS will occur only when the altimeter signal and the PAVE PAWS signal are close enough in frequency to permit their difference frequency (delta f) to pass through the altimeter's audio-frequency amplifier. Siemen (1977) points out that during the brief interference periods, the difference frequency sweeps from high values of delta f through zero frequency and back through high values of delta f. The metering system operates so that it responds very rapidly to the high delta f of the interfering signal, but when the interference is removed it relaxes so slowly that it takes about 0.5 s to recover. While under the control of the PAVE PAWS signal, the altimeter will

attempt to read high (because high delta f also implies high altitude). The extent to which the meter will read high depends on the audio-frequency amplifier's rejection of increasingly high frequencies and on the duration of the interference each time it occurs.

Apparently, a PAVE PAWS signal 10 dB above the altimeter's return signal would control the altimeter. However, the ECAC analysis (Siemen, 1977) provides no information on the expected level of the AN/APN-1 altimeter's input signal other than to say that the threshold level is -87 dBm. Without calculations of received power levels or of the levels of the PAVE PAWS signal that would lead to degrading effects, it is impossible to predict the distance that an aircraft equipped with the AN/APN-1 must be from PAVE PAWS to operate without interference. Siemen says that approximately 190 miles would be sufficient when the aircraft is at 4,000 ft (the maximum altitude for this altimeter). Perhaps even a closer distance would be sufficient, however, because the radio horizon for an aircraft at 4,000 ft is about 100 miles.

C.3.1.5.2 *Other Aids to Navigation*. Radio-operated aids to air navigation, maintained throughout the United States, consist of ground stations and equipment in the aircraft. Ground stations are located in the vicinities of both Robins AFB and Moody AFB, and aircraft using them will be illuminated by PAVE PAWS. Nevertheless, effects at ranges greater than a mile or so from PAVE PAWS do not appear likely on the basis of the meager measurements available.

C.3.1.5.2.1 TACAN and DME. In these extensively used systems, aircraft use radio transmissions between themselves and a ground station to determine two items of information: the distance to the ground station, and the bearing to it. The methods and frequencies of the distance measuring equipment (DME) are identical for military and civilian aircraft, and both can use the same ground stations. Aircraft using the military equipment, Tactical Air Navigation System (TACAN), can extract both distance and bearing from a TACAN ground station. Civilian aircraft can use the TACAN ground station with their DME systems to measure distance. They obtain bearings from a VHF Omnirange (VOR) collocated with the TACAN beacon. Such a collocated VOR/TACAN system is called a VORTAC.

The VOR system operates in the 108- to 118-MHz band (just above the FM broadcast band and far below the PAVE PAWS band). TACAN and DME operate in the band from 960 to 1,215 MHz. Each of the VOR frequencies is paired with a set of DME uplink and downlink frequencies. The VORTAC or TACAN stations within about 50 miles of both potential PAVE PAWS sites are listed in Table C-14. Second and third harmonics of PAVE PAWS are in the 840- to 900-MHz and 1,260- to 1,350-MHz bands, respectively, so they can be ruled out as an interference mechanism to TACAN. Moss (1978) mentions that spurious responses involving the second harmonic of the TACAN receiver's local oscillator and the fifth harmonic of the PAVE PAWS signal are possible. That type of spurious response will be of concern only for the airborne receivers. Even so, harmful interference is not expected, for the following reasons. First, only 1 of the 24 PAVE PAWS frequencies would be involved, and a main-beam pulse at that frequency

Table C-14

VORTAC/DME STATIONS IN THE TWO POTENTIAL PAVE PAWS AREAS

Call Letters	Channel	Location	Operating Frequencies (MHz) Uplink	Downlink	Spurious-Response Frequencies in Aircraft[a] (MHz) Solution A	Solution B
Near Robins AFB						
MCN	89	Macon	1,175	1,112	457.4	432.2
DBN	78	Dublin	1,165	1,102	453.4	428.2
VNA	112	Vienna	1,199	1,136	467.0	441.8
Near Moody AFB						
VAD	80	Moody AFB	1,167	1,104	454.2	429.0
AMG	98	Alma	1,185	1,122	461.4	436.2
AYS	39	Waycross	1,000	1,063	437.8	412.6
TAY	76	Taylor	1,163	1,100	452.6	427.4
VLD	41	Valdosta	1,002	1,065	438.6	413.4
GEF	36	Greenville	997	1,060	436.6	411.4
MGR	25	Moultrie	986	1,049	432.2	407.0
IFM	72	Tifton	1,159	1,096	451.0	425.8

[a] $F_{sp} = \frac{1}{q} \text{abs}(pF_{LO} \pm F_{IF})$, where p = 2, q = 5.

This equation yields two solutions. Calculating F_{sp} using the plus sign yields solution A; calculating F_p using the minus sign yields solution B. (Frequencies of concern are underlined; those not underlined are outside the PAVE PAWS band.)

would illuminate the aircraft only about once every 34 s. Second, the airborne DME receiver is designed to ignore pulses other than the ground-station returns of its own downlink pulses. Thus, an occasional spurious pulse should present no problem. Finally, spurious response rejection in TACAN receivers is at least 92 dB to frequencies in the 420- to 450-MHz band.

Some tests have been made on two airborne units: a military TACAN system and a DME-70 for military or general aviation. High-power effects were not noted on either unit at the maximum available power density levels in the 420- to 450-MHz range. These maximum levels were 37 dBm/m^2 for the TACAN receiver and 43 dBm/m^2 for the DME receiver (0.5 and 2.0 mW/cm^2, respectively). Such pulse power densities can be produced by the first sidelobe only within about 2 miles (see Figure C-13),

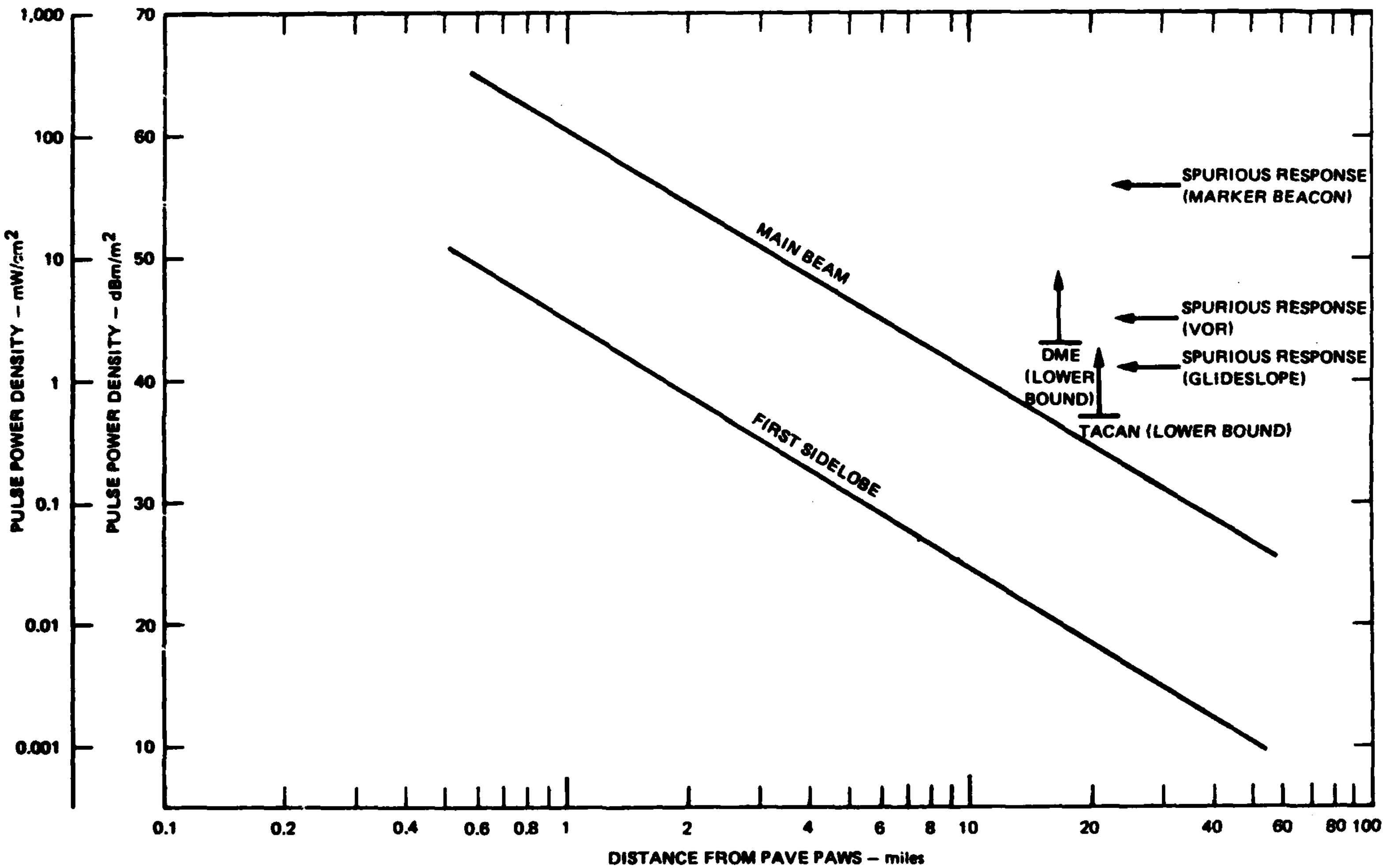


FIGURE C-13 SUSCEPTIBILITY THRESHOLDS (AND LOWER BOUNDS) FOR SOME AIRBORNE ELECTRONIC SYSTEMS

or within the main beam at distances less than about 7 to 15 miles. Further, the region of interest is essentially limited to the surveillance volume. Because the susceptibility thresholds are known to be greater than the power density numbers just mentioned as lower bounds, the aircraft may well be able to come closer than 15 miles in the mainbeam surveillance volume with no effect. When in the main-beam surveillance volume an aircraft would be illuminated by the main beam about once every 1.4 s. (Surveillance pulses account for that rate; PAVE PAWS radars will not track aircraft, and SEPP devotes only a small fraction of its resources to tracking.) If affected only so infrequently, the TACAN/DME airborne interrogator may only momentarily lose lock and switch from its tracking mode of operation to its searching mode.

C.3.1.5.2.2 Miscellaneous Systems. Measurements of high-power effects have been made on some other air-navigation aids (see Table C-15). The units were tested with desired-signal levels representing either realistic maximum use distances or design-maximum distances for the receivers. The susceptibility thresholds quoted are all for antenna-coupled interference, based on laboratory measurements and an assumption of the gain of the victim system's antenna to the interfering signal. The susceptibility levels will probably increase under most circumstances, because the systems will be receiving higher levels of desired signals than indicated.

Even so, with the susceptibility thresholds of Table C-15 placed on the power density plot of Figure C-13, it does not appear likely that airborne nagivation systems of these types will suffer interfering effects from PAVE PAWS.

Table C-15

HIGH-POWER EFFECT THRESHOLDS FOR SOME AIRBORNE NAVIGATION SYSTEMS

Equipment	Frequency (MHz)	Desired Signal Level (dBm/m^2)	Slant Range (nmi)	Susceptibility Threshold for 420-450 MHz Signals (dBm/m^2): Spurious Response	Susceptibility Threshold for 420-450 MHz Signals (dBm/m^2): Wideband Response
VOR	108.1	-66	150	45	Greater than 73[a]
Glideslope	330	-65	20	41	Greater than 73
Marker Beacon	75	-49	2	56	Greater than 73

[a]Maximum available power density.

C.3.1.5.3 Instrumentation in Helicopters. PAVE PAWS at Otis ANG Base (essentially identical to the proposed SEPP installation) was observed to produce false indications in instruments in helicopters. Two Army OH-58A helicopters each noted misleading indications in their instruments as they approached to within about 1.6-1.9 miles (2,500-3,000 m) of the radar and within the main-beam surveillance volume. They had previously received clearance to enter the restricted area. In both helicopters, the fuel gauge indicator suddenly began to register falsely high, and at the same time, the pilots were alerted by lights and an audio alarm meant to indicate low engine RPM. These instruments are designed to alert the pilot to a potential engine (or rotor) failure. The pilots quickly realized that there were no engine problems and that the alarm indications themselves were erroneous. The actual performance of the helicopters was unaffected.

The helicopters, at a range of about 2 km, were being illuminated with pulse power densities of about 48 dBm/m^2 (6.3 mW/cm^2). The effects depended on the orientation of the helicopter relative to the radar; they ceased as the helicopters turned away from PAVE PAWS. These are examples of high-power effects. The fuel gauge problem in OH-58A helicopters is not new; that gauge is also known to give false indications when an onboard AN/ARC-114 FM radio is keyed on.

The Federal Aviation Administration (FAA) is active in investigating potential problems in air navigation. The FAA made flights on 9 and 10 February 1979, near Otis ANG Base, to test the effects of the radar on several air navigation instrument types. No abnormalities of the cockpit instruments were noted. The FAA trip report concludes, "Since the radar's burst of RF energy occurs for only a fraction of a second on a specific frequency, and appears to occur only one time in several minutes, it is concluded that the radar does not present potential interference to our navigational facilities" (Allbright, 1979).

Further tests were conducted at Otis ANG Base on 22 March 1979, with helicopters carrying measurement instrumentation. The tests involved the Massachusetts National Guard and the U.S. Coast Guard, and it was learned that the Coast Guard helicopters were not affected as close as the 1,000-ft exclusion fence. A low-rpm indicator light in a UH-1 helicopter flashed when the chopper was within about 1 mile of the radar. Work began immediately to establish procedures for Army helicopters operating near that radar, and a Notice to Airmen (NOTAM) was issued as follows:

NOTAM

> "Aircraft operating below 2,000 feet and within three miles of the PAVE PAWS radar site located in restricted area 4101, Bourne, Mass., may experience momentary erratic operation of cockpit instruments or navigational equipment. Pilots are encouraged to submit reports of such occurrences to the nearest FAA Air Traffic facility."

The main beam of SEPP is about 10 times more powerful than that of the PAVE PAWS at Otis ANG Base; therefore, the same kinds of disturbances can be expected to occur in the vicinity of SEPP and at substantially greater distances.

C.3.1.5.4 Air-to-Ground Communications. The band between 225 and 399.9 MHz is used for UHF/AM voice communications between aircraft and ground. The upper edge of this band is at least 20 MHz below the lowest PAVE PAWS frequency. When the ground station is located near the PAVE PAWS radar, there are two potential victim receivers: the one on the ground, and the one in the aircraft. However, experience shows that interference with air-to-ground communications has not been a problem at the two presently operating PAVE PAWS radars, and so no detailed study was considered necessary for SEPP.

At Beale AFB, the ground-based transceiver is illuminated by the first and the higher order sidelobes of the PAVE PAWS radar at a distance of approximately 4 miles (7 km) directly in front of PAVE PAWS; the ground-based equipment at both Robins AFB and Moody AFB is located at comparable distances from, but behind, the SEPP location. There it can be reached only by weak, scattered, and diffracted PAVE PAWS energy that is further attenuated by the thick trees. Thus, the Robins and Moody ground-based receiving systems are positioned much more favorably with respect to the PAVE PAWS radar than is the Beale AFB system. Because no interference to the Beale system has occurred, none is expected for the Robins or Moody system.

The airborne equipment near all PAVE PAWS locations is, of course, subject to illumination by the radar's main beam. For ground-to-aircraft communications from these air bases, the ground-based transmitter and the PAVE PAWS radar are generally close enough to be considered collocated, so distance is not a factor in considering the signal-to-interference ratio at the aircraft. At frequencies at least 20 MHz below the lower edge of its band, the PAVE PAWS signal that reaches the aircraft will not be strong relative to the desired signal. Even the main beam is of no major concern; since PAVE PAWS will not track aircraft, the plane would be illuminated only incidentally. If in the surveillance volume, it would be illuminated by the main beam only about once every 1.4 s; in any other location, main-beam illumination is very unlikely since SEPP is intended to do almost no tracking. Thus, SEPP is not likely to affect the communications to the aircraft from the Robins or Moody ground station.

C.3.1.6 Harmonically Related Bands

Harmonics of a desired frequency can be generated by nonlinearities in amplifiers or other circuits. If nonlinearity is present in a transmitter or receiver, harmonic frequencies, particularly odd harmonics of the fundamental, can be expected in the output signal. In a transmitter, the ratio of the magnitude of the fundamental with respect to the magnitudes of such harmonics is termed the harmonic suppression ratio and is generally specified in decibels. Harmonic and spurious-frequency

suppression for PAVE PAWS has been specified to be at least 90 dB; that is, harmonic and spurious-frequency power is less than that of the fundamental frequency by a factor of 1/1,000,000,000 (90 dB). Under such a specification, the radiated power for harmonics and spurious signals of the PAVE PAWS system (for signals near the surface of the earth) would not exceed +30 dBm (less than 1 W) for the first sidelobe, and +27 dBm for the second sidelobe. The power in the harmonic decreases as the order of the harmonic increases, so that the power of third or fourth harmonics would generally be much less than the above figures.

In general, the probability of interference to receivers operating at frequencies harmonically related to those in the 420-450 MHz band is small. Such a low probability results from (1) the excellent harmonic suppression specified for the radar, (2) significantly higher basic transmission loss for the harmonic frequencies compared to the fundamental (where the concern is with the harmonic signal itself propagating), and (3) receiver rejection of out-of-band signals that could cause in-band harmonics within the receiver. Finally, communication systems in the microwave portion of the spectrum (where the PAVE PAWS harmonics fall) are generally used for point-to-point communication. They generally employ directional antennas aligned to the communication path so as to attenuate electromagnetic energy arriving from other directions.

The following sections briefly discuss the frequency bands that are harmonically related to those of the PAVE PAWS system and the types of systems that occupy those bands. Although no analysis was conducted, the likelihood of interference seems remote.

C.3.1.6.1 420-450 MHz. This band is the fundamental (first harmonic) of the PAVE PAWS band. Radar altimeters and the Amateur Radio Service have already been discussed (see Sections C.3.1.1 and C.3.1.5.1). Other radar systems also use this band, as do some telemetry systems.

C.3.1.6.2 840-900 MHz. The second harmonics from PAVE PAWS fall in this frequency band, which is allocated to nonfederal-government land mobile users. The portion from 825 MHz to 890 MHz is to be occupied by the new cellular land-mobile radio-telephone system. Only two such experimental systems are currently operating (in the Chicago and the Washington areas). Atlanta will eventually have a cellular system, which will probably be the one closest to Robins AFB. The cellular system, with its many available voice channels, is highly resistant to interference. It is not likely that a cellular system would be installed near Moody AFB.

C.3.1.6.3 1260-1350 MHz. The third harmonics from PAVE PAWS cover this frequency range, which is allocated to government and nongovernment radars or aeronautical radio-navigation equipment. (The Amateur Radio Service is also permitted to use the lower part of this range--up to 1300 MHz--but only on a not-to-interfere basis.) According to ECAC, no aircraft radar uses this frequency band (Siemen, 1978).

C.3.1.6.4 1680-1800 MHz. The fourth harmonics of PAVE PAWS channels fall within this frequency range, which includes bands used by radiosonde

meteorological aids, meteorological satellites, and government line-of-sight microwave links.

C.3.1.6.5 2100-2250 MHz. This portion of the spectrum, where the fifth harmonics of the PAVE PAWS channels fall, includes a portion of the common carrier line-of-sight microwave band as well as some spectrum reserved for government use. PAVE PAWS would be unlikely to cause interference to receivers operating in those bands unless the radar is actually along the line between the two sites and located quite close to one end so that the antenna at that site is directed at the radar.

C.3.2 Hazard Effects

The potential effects of PAVE PAWS electromagnetic fields on equipment other than telecommunication systems are termed hazard effects. Three potentially dangerous situations that high amplitude RF fields can cause under certain circumstances are interference with the normal operation of implanted cardiac pacemakers, accidental detonation of electro-explosive devices (EEDs), and ignition of liquid fuels as they are being handled. Other implanted or attachable medical prosthetic devices are principally in the developmental or prototype stage so that information on their susceptibility to interference is scarce. The implantable devices are to have the same resistance to interference as have modern pacemakers (Toler, 1982).

C.3.2.1 Cardiac Pacemakers

Cardiac pacemakers are potentially subject to electromagnetic interference, leading to the concern that a PAVE PAWS radar could affect pacemaker wearers in the air or on the ground in its vicinity. Whether SEPP will affect pacemakers depends on the susceptibility of the individual device and on the level of the SEPP signal that reaches it. The likelihood is very small that a pacemaker owner, either on the ground or in the air, would enter a potentially dangerous region or could remain there long enough to be affected. Thus, the possibility of interference is remote.

C.3.2.1.1 Background. The heart can be considered to be an electrically operated pump. It is a set of muscles that contracts rhythmically in response to a periodic electrical impulse that originates naturally in a certain portion of the cardiac tissue. Some people who suffer impaired operation of that natural pacemaker or of the conducting paths in the cardiac tissue rely on an artificial pacemaker, which supplies the electrical signal to make the heart beat when it should. Hundreds of thousands of people in the United States have pacemakers.

Although four general types of cardiac pacemakers are employed, by far the most common (80 to 90% of the pacemakers in use) is the R-wave inhibited type. The R-wave inhibited (synchronous) pacemaker supplies a pulse only on demand (i.e., when the heart requires it). It senses the natural electrical signal of the main pumping action of the heart. If that natural signal fails to occur when it should, the pacemaker supplies

the signal to trigger the heart's action. Although R-wave inhibited pacemakers are generally more susceptible to electromagnetic interference than are the other types, great progress has been made in recent years in reducing that susceptibility.

Pacemakers do not fail permanently when exposed to strong RF fields; instead, if the field is sufficiently intense, they may exhibit one of four types of dysfunction, of which the most common (for a synchronous pacemaker) is termed "reversion." This means that the pacemaker reverts to a benign fixed rate; it is designed to respond to RF by becoming, for the time being, an asynchronous pacemaker. Reversion is not always even considered a form of dysfunction. In fact, for purposes of monitoring the pacemaker's fixed rate (and thus the battery condition), a pacemaker owner frequently will cause his pacemaker to assume that condition.

C.3.2.1.2 Susceptibility to Pulsed RF Fields. There is a device-dependent threshold of field intensity above which a pacemaker will react to RF pulses. According to Denny et al. (1977), at low PRFs (less than 10 pps) an R-wave inhibited pacemaker is likely to misinterpret such pulses as the heart's electrical activity and to become inhibited. At higher PRFs, it is more likely to revert to asynchronous operation. Long-term inhibition (for durations greater than about five normal heartbeats) may constitute a health hazard for some owners, whereas reversion to fixed-rate pacing is less serious.

Although considerable research was conducted and many papers were published on pacemaker susceptibility to electromagnetic fields in the mid and late 1970s, this activity has since greatly decreased. Among the principal reasons is that a pacemaker susceptibility standard was developed in 1975 (AAMI, 1975). In accordance with that standard, the pacemakers now being marketed are capable of unaffected operation in pulsed field strengths in excess of 200 V/m. Susceptibility testing has now become routine, with the Biomedical Research Division of the Engineering Experiment Station of Georgia Institute of Technology conducting that work for all but one of the major U.S. manufacturers, as well as for many of the major foreign manufacturers (Toler, 1982).

The latest draft verision of the AAMI pacemaker standard describes various performance tests, but has dropped all reference to EMI susceptibility testing (AAMI, 1981). According to the cochairman of the AAMI pacemaker committee, this was done for several reasons. One was to make the U.S. standard more similar to an international standard so as to facilitate trade. Another reason was that the committee felt that a rigid EMC standard could encourage manufacturers to produce pacemakers with EMI susceptibility no better than the minimum requirements of the standard (Flink, 1982). He agrees that the modern pacemakers are almost invulnerable to electromagnetic interference.

The susceptibility of the older pacemakers to RF fields at or near 450 MHz was measured by several researchers. Schlentz et al. (1976) showed that results of tests with the pacemaker immersed in saline solution are entirely equivalent, at 450 MHz, to results using implanted

pacemakers. In either situation, the field strengths are defined and measured in the air outside the body or the saline solution. Denny et al. (1977) stated then that pacemakers had become noticeably less susceptible in the preceding few years. They described the results of measurements of susceptibility thresholds for pacemakers in saline solution, which is the method used in the 1975 version of the standard and currently used by the Georgia Tech workers. Their published results included old and new pacemakers, as well as prototypes that may not have gone into production (Denny, 1978; Toler, 1978).

The pulse-susceptibility data available in the literature (Denny et al., 1977; Mitchell et al., 1975; Mitchell and Hurt, 1976) must be interpreted with caution because it may no longer apply. For example, the published version of the work of Denny et al. (1977) does not mention that their plots of susceptibility thresholds were developed using many prototype or developmental pacemakers, some of which did not go into production as tested because of the low susceptibility thresholds shown in the paper. Thus, although that paper showed the results of many tests, the data do not necessarily represent the susceptibility thresholds of the pacemakers that had, at that time, actually been manufactured and implanted in cardiac patients.

Susceptibility levels, based on 450-MHz tests in August 1975, were published by Mitchell and Hurt (1976). That report states that the susceptibility levels (ranging from 4 V/m to more than 260 V/m) "are believed most representative of the current state of technology" (for 1975). The report also states that "if pacemakers were designed and tested to be compatible with the minimum E-field level, viz 200 V/m, associated with the unrestricted 10 mW/cm^2 personnel exposure level, potential EMI situations would be substantially reduced or effectively eliminated." Such a 200-V/m testing level, described in the 1975 standard prepared by the Association for the Advancement of Medical Instrumentation (AAMI) for the Food and Drug Administration, is now in general use (AAMI, 1975). The pacemaker is submerged in a tank of saline solution to simulate body tissue and its catheter is aligned for maximum coupling with the electromagnetic field. Testing is to be done at but not necessarily above 200 V/m, within 50 MHz of 450 MHz, and at pulse repetition frequencies of 125% $\pm$ 10% of the basic rate of the pacemaker.

Both Mitchell (1978) and Denny (1978) suggested that the manufacturers were then probably meeting the 200-V/m level in their newer models. Some preliminary data from measurements by Mitchell in 1977 indicated that many were not susceptible at levels as high as 330 V/m. Denny stated in 1978 that the threshold for most of the newly released pacemakers was above 300 V/m. Toler (1982) believes that none of the pacemakers released in 1982 are susceptible to fields of 200 V/m.

Manufacturers we contacted in an informal 1978 survey for the EIS for the PAVE PAWS at Beale AFB stated that their newer pacemakers met the 1975 AAMI standard. One manufacturer said that the manual for a particular model stated that it had been tested to 295 V/m.

By now, few if any of the older pacemakers, described in the literature of 4 or 5 years ago, would still be functioning, so the susceptibility thresholds of the pacemakers currently in use are probably quite high. Older pacemakers are being replaced with newer ones because an entirely new pacemaker must be implanted in an individual when the battery becomes exhausted; thus, the physician has an opportunity to implant a pacemaker less susceptible to electromagnetic interference. When mercury cells were the only types of battery used, pacemaker replacement was necessary about every 2 to 3 years; lithium iodide batteries last 6 to 8 years or more and are now essentially the only type used.

C.3.2.1.3 Susceptibility to PAVE PAWS. A pacemaker that may be susceptible to a field of a certain level when tested in the laboratory, will not necessarily react to that same field when implanted. Pacemaker susceptibility testing is done with the pacemaker's catheter extended and aligned for maximum coupling with the 200-V/m electromagnetic field. However, an implanted pacemaker's catheter is neither extended nor is it necessarily optimally aligned with the field, a circumstance that decreases the actual susceptibility of an implanted pacemaker. Normal minor shifts in body attitude relative to an impinging electromagnetic field can also cause great changes in the susceptibility of a pacemaker. Thus, even if a pacemaker owner could enter the region where the PAVE PAWS field exceeds 200 V/m, other circumstances would still make extended durations of pacemaker dysfunction unlikely, so that harmful effects on the pacemaker's owner would be unlikely.

A pacemaker owner who approaches PAVE PAWS on the ground will not be exposed to the fields from the main beam. At the close distances of interest, only the second and higher order sidelobes will illuminate the ground. Thick forest and underbrush prevail in the area directly in front of the radar site at Robins AFB; in contrast, the area directly in front of the Moody AFB site is bare except for the grass growing on the abandoned air field. The thick forest surrounding PAVE PAWS at Robins AFB would attenuate the PAVE PAWS signal, which would not be the case at Moody AFB. However, at neither site would there be any areas outside the 1,000-ft exclusion fence where the pulse field strength exceeds 200 V/m. Thus, it appears unlikely that PAVE PAWS poses a hazard to a pacemaker owner who may approach the exclusion fence.

Aircraft in flight within 3.5 miles of the radar and in the surveillance volume will occasionally be illuminated with pulses exceeding 200 V/m (10 mW/cm^2). The volume probed by the PAVE PAWS main beam in the surveillance mode is defined by a 3 deg beam elevation angle, its 1.3-deg beamwidth, and the 240-deg azimuthal coverage of PAVE PAWS. Many of the flight tracks at both Robins AFB and Moody AFB pass through this volume. When within it, the aircraft will be illuminated with a pulse from the main beam approximately once every 1.4 s (or at a rate of about 0.7 pps).* Outside this narrow volume, the aircraft will almost never

*These numbers depend on the final design of the radar. They may change, but not significantly.

be illuminated by the main beam since SEPP devotes very little time to tracking.

This illumination of aircraft is not considered to be a threat to pacemaker owners for a number of reasons. First, the 200-V/m level used for laboratory susceptibility testing does not have any direct relevance as a field strength incident on aircraft that could possibly carry passengers with implanted pacemakers. The body of the aircraft provides some amount of shielding, so that the fields experienced by the aircraft's occupants would be lower than the fields incident on the aircraft. Further, few, if any, pacemaker owners would be likely to ever be in that airspace in front of the radar. Traffic into Robins AFB and Moody AFB is composed almost entirely of military aircraft with military crews, who would not be dependent on pacemakers.

Finally, if we were to grant that there were individuals with pacemakers in aircraft closely in front of the radar, that the fields were sufficient to affect the pacemaker, and also that the individual was dependent on the action of the pacemaker at that particular time, we would then want to consider the nature of the effect on the pacemaker and the pacemaker owner. The pacemaker would probably interpret the isolated PAVE PAWS pulses and pulse groups as R-wave activity, so that it would be inhibited for about 900 ms after each such pulse. Most physicians would suggest that one missed beat in ten would be acceptable. Pulses would impinge quite frequently on an aircraft in the surveillance volume. However, this volume is quite small and an airplane would not spend much time there. At a distance of 3.5 miles or less from the radar, airplanes higher than 1,200 ft above the ground are above the surveillance volume. At both Robins AFB and Moody AFB, the major glideslope passes downward through the surveillance volume less than 3.5 miles from the radar, but the landing aircraft would traverse that volume in only a fraction of a minute. During that time, they would be illuminated with pulses stronger than 200 V/m at a rate of about 0.7 pulses per second. If each of these pulses could inhibit the pacemaker for 900 ms, the pacemaker would be inhibited for more than half of its normal beats during that fraction of a minute, which could be significant according to the above criteria.

In summary, PAVE PAWS is unlikely to be a threat to owners of cardiac pacemakers on the surface outside the exclusion fence or in the sky in front of the radar.

C.3.2.2 Fuel Handling

The military has long been concerned over the possibility that high-powered radars (such as those on an aircraft carrier) could ignite volatile fuels as they are transferred. Ignition would result if the high RF fields caused a spark across a gap in a fuel-air mixture. Experiments have determined the dc spark energy required to ignite fuel. According to the AF Technical Manual T.O. 31Z-10-4 (1971), "The amount of RF voltage required to break down a similar gap is unknown but is believed, until proven otherwise, to be approximately the same as the

dc-voltage value." For fuel handling near a radar, "a peak power density of 5 W/cm^2 (5,000 mW/cm^2) or less can be considered safe."

Fuel-handling operations at Robins AFB and Moody AFB would take place behind the PAVE PAWS radar at distances greater than 3 miles in both cases. The PAVE PAWS field strengths there (from Figure C-5) are estimated to be less than 2 dBm/m^2 (1.6 mW/m^2, 0.00016 mW/cm^2). This is a factor of 31,000,000 lower than the maximum safe power density of 5,000 mW/cm^2. The maximum power density that would ever occur near the ground, even directly in front of a PAVE PAWS face at any distance, is less than 100 mW/m^2, which is still a factor of 50 less than the maximum safe level. PAVE PAWS will not pose a hazard to fuel-handling operations at either of the two bases.

C.3.2.3 Electroexplosive Devices

C.3.2.3.1 Types of EEDs. EEDs are used to activate secondary explosive charges, ignite propellant systems, and actuate electroexplosive switches. EEDs are used in aircraft systems to jettison flares and wing tanks while in flight, release externally carried missiles, and in some aircraft, activate ejection seats. There are still other applications, and the use of EEDs on modern military aircraft is common. The four basic types of EEDs, actuation mechanisms, and uses are as follows (Hovan, 1978):

- Exploding bridgewire: This type requires a high-energy capacitive discharge pulse to explode bridgewire.
- Normal bridgewire: An explosive mix is glued to the bridgewire; electrical current heats the bridgewire, detonating the adhesive primer.
- Composition mix: This type uses conductive explosive mix; the current passes through the mix, igniting it.
- Carbon bridge type: This type, used internally in three or four weapons systems and in 20-mm cartridge primers, could be sensitive to RF fields and to static electricity.

All EEDs are ignited electrically and hence are subject to accidental ignition from the following causes:

- Lightning discharge. Lightning protective systems normally preclude the inadvertent ignition of EEDs by direct lightning strikes.
- Static electricity discharge. This is a hazard mainly for ground operations.
- Stray energy, such as transients and other forms of induced conducted energy, from other on-board electrical equipment.

- Radiated fields from RF emitters. If the RF field is strong enough, it can induce currents that will cause the EED to fire.

C.3.2.3.2 Electromagnetic Field Safety Standards for EEDs. EEDs are susceptible to ignition by exposure to radiated fields. The degree of susceptibility depends on many variables: the safe no-fire threshold of the EED, the ability of the EED leads to capture RF energy, the frequency and power density of the RF energy, and the condition of exposure of the EED--whether contained in a shielded cannister, mounted inside an aircraft with partial shielding provided by the skin of the aircraft, or exposed to the environment with no shielding present. The Air Force safe exposure criterion is expressed either as a safe average power density, in W/m^2, or as a safe separation distance. As the distance, d, between an EED and the RF transmitter is increased, the power density at the EED decreases at least as rapidly as $1/d^2$.

The safe separation distances specified by AF Regulation 127-100, Explosive Safety Standards, are based on a worst-case situation; that is, on the most sensitive EED currently in inventory, unshielded, and having leads or circuitry that could inadvertently be formed into a resonant antenna (USAF, 1978 and 1982). The criteria apply generally to critical areas involving explosives assembly, disassembly, testing, loading, and unloading operations, and are based on the safe, no-fire threshold of the EED. Exceeding that threshold does not imply that the EED will fire. The actual firing threshold of the EED may be several orders of magnitude above the safe no-fire threshold.

The AFR 127-100 criteria for safe power flux density exposure for EEDs are summarized for several EED configurations in Table C-16. All safe exposure limits are given in terms of average power density at 420 MHz. (For some of the configurations, the recommended maximum power density is frequency-dependent, and use of the lowest PAVE PAWS frequency yields the lowest, most conservative, maximum power density.)

C.3.2.3.3 PAVE PAWS as a Special Case. The average power density criterion of AFR 127-100 should not be directly applied to a PAVE PAWS radar without consideration of the differences between such a radar and a conventional radar. In fact, the conventional definition of a radar's average power does not seem appropriate for use with the standard when the radar under consideration is a PAVE PAWS radar. The argument in the following paragraphs hinges on the appropriate time duration over which to average the radar's power density. Although AFR 127-100 does not make this point, it seems reasonable that the averaging time should be no longer than the critical time in which there could be an irreversible effect on the EED (i.e., its detonation). After all, if the EED fires during a certain interval, any subsequent time, when the radar is "off" or its beam is directed elsewhere, is of no concern and should not be considered in calculating an average power. To draw an obvious analogy: You cannot wade across a river having an average depth of only 1 ft if your first step drops you into a hole 10 ft deep; the shallowness of the rest of the crossing is of little interest. One Air Force manual, T.O.

Table C-16

SAFE EXPOSURE LIMITS FOR EEDs AT PAVE PAWS FREQUENCIES

Exposure or Storage Condition	Average Power Density W/m^2	Average Power Density mW/cm^2	Average Power Density dBm/m^2
EEDs in exposed condition (this also applies for any "unknown worst case" situation).	0.75	0.075	28.8
EEDs in storage or transport, in metal containers, leads shorted	100	10	50
EEDs in storage or transport, in nonmetallic containers, leads shorted	7.5	0.75	38.8
Aircraft parked or taxiing with externally loaded weapons	75	7.5	48.8
Aircraft in flight with externally loaded weapons, or shipment of EEDs inside cargo aircraft	100	10	50
Leadless EEDs in original shipping configuration	(No max. power density; minimum distance: 10 ft)		
Leadless EEDs during handling and installation	0.75	0.075	28.8

Source: Explosive Safety Standards, AF Regulation 127-100 (currently being revised)

31Z-10-4, states that when sufficiently large currents are applied to some EEDs, detonation may occur within microseconds (USAF, 1971).

Current flowing through an EED causes it to heat; when the current stops, the heat dissipates. A radar typically turns its pulses on and off. The time from one pulse to the next is termed the radar's period. If the heat energy accumulated in an EED when a pulse is present exceeds that which can be dissipated when the pulse is off, there is a net increase in heat during the period and the EED may eventually fire. The temperature increase during a pulse is proportional to the energy per pulse (the product of the pulse power and the pulse length). The temperature drop (energy loss) depends on, among other things, the time

interval to the next pulse. Thus, the energy per pulse and the interval between pulses are both important. The average energy per period is the product of the average power and the duration of the period.

A conventional radar has a pulse width of a microsecond or so, and a PRF of around 1000 pps. The period is typically about a millisecond. Although the pulse power may be high, the energy per pulse is relatively low because the pulse is short. Not only would exposure to many pulses be required to accumulate sufficient heat energy to detonate an EED; also, each successive interpulse interval would allow for some cooling. The average power for a conventional radar is an average calculated over a single radar period, and this brief averaging period seems appropriate if an exposure to many radar periods would be required to accumulate the energy to detonate the EED.

On the other hand, many of the PAVE PAWS pulses are 5,000 and 8,000 microseconds long, so that if the pulse power is high, the energy per pulse will be much larger than for a conventional radar. Thus, if the pulse power density is high enough, there may be more than sufficient time for an EED to fire within the duration of a single PAVE PAWS long-range surveillance pulse. In the case of an aircraft in flight, such a pulse would illuminate the aircraft on the average of only about every 4 s, although this does not imply that these long pulses would occur regularly spaced every 4 s. At angles greater than about 45 deg from a SEPP face's boresight, the 8,000-microsecond pulses would illuminate an aircraft at an average interval of about 1.5 s, although sometimes the interval would be as short as about 0.6 s. Also, other, shorter pulses would hit the aircraft more frequently. It is hardly reasonable to average PAVE PAWS power over, say, a 4-s period if essentially all the energy is deposited in a single 8,000-microsecond interval, and if this 8,000-microsecond interval is long enough to detonate an EED.

Thus, the averaging duration should be no longer than the critical time in which an EED could be detonated and should not be dictated by the timing characteristics of the radar in question. That critical time is so long that, for a conventional radar, the normal definition of the radar's average power is appropriate; one averages over a radar period. However, that critical time is so short relative to a PAVE PAWS "period" that one should average the PAVE PAWS power over the duration of the pulse itself, thus obtaining the pulse power of the PAVE PAWS radar.

Using the PAVE PAWS pulse power is a more conservative approach in that the safe exposure distances found that way would be considerably greater than those found using the radar's average power density.

Figure C-14 compares some of the safe exposure limits for ground-based situations with estimated SEPP pulse power densities that could occur near the ground. Because the main beam and the first sidelobe are not near the ground, the ground in front of the radar could be illuminated by the second sidelobe; behind the radar, exposure is by scattering and diffraction only. These two curves both are lower than free-space values by 10 dB to account for some power loss in the foliage.

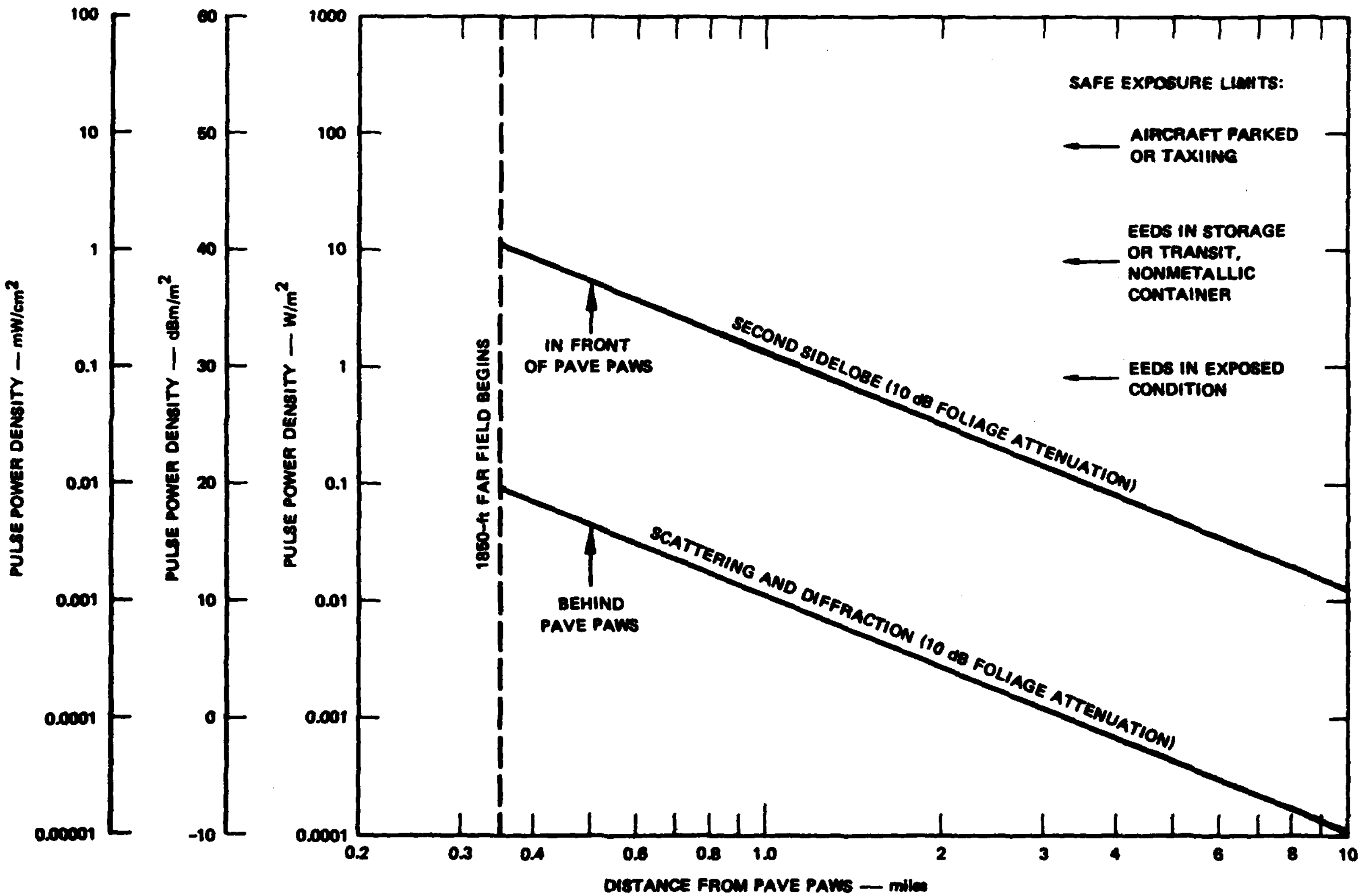


FIGURE C-14 SEPP SIGNAL STRENGTHS AND SOME SAFE EXPOSURE LIMITS FOR EEDS

Figure C-15 compares the safe exposure limit for aircraft in flight with the pulse power densities for the surveillance volume. The pulse power density on an aircraft at distances less than about 3.5 miles exceeds 100 W/m^2 for durations up to 8 ms when the aircraft is illuminated by the main beam. Air Force experts do not believe that this is a hazard (Hovan, 1982).

C.3.2.3.4 EEDs at Robins AFB. EEDs are present on aircraft and in various storage areas at Robins AFB. The normal handling and storage areas for EEDS are all located 2 miles or more to the north of the SEPP radar; that is, behind it. (It is also conceivable that EEDs could be transported past the front of the radar on Highway 247.) Some of these areas are listed in Table C-17, which also shows applicable safe exposure limits and the estimated pulse power density from the SEPP radar--as taken from Figure C-14. The safe exposure limits on the table are the most stringent that might be applied. In all cases, the estimated pulse power density from the radar is well below the safe exposure limits, although only by a factor of about 3 at the highway. Average power densities at all these places are, of course, far below the pulse power densities.

EEDs of various sorts are carried on aircraft that operate out of Robins AFB. There are several basic flight patterns for arrival and departure, which are shown on Figure C-16. That figure shows a plan view of the volume within which the main-beam pulse power density occasionally exceeds 100 W/m^2 for durations of 5 or 8 ms. (The safe exposure limit for aircraft in flight is an average power density at that same level for an unspecified exposure duration.) Figure C-17 is a vertical-plane cross section of the normal glide path to determine where aircraft using the tracks labeled 32C, 32D, and so on would pass downward through the radar's normal surveillance volume and be exposed to pulse power densities in excess of 100 W/m^2. The glide path shown there is at an angle of 2.5 deg, as the Robins Air Installation Compatible Use Zone (AICUZ) report states is established for both runways (USAF, 1982). It can be seen that aircraft on that glide slope pass through the surveillance volume about 2 miles from the end of the runway and at a distance of only about 1.5 miles from the radar. From Figure C-15, the pulse power density there is about 57 dBm/m^2 (500 W/m^2), or five times the recommended average power density limit for aircraft in flight. In part of the approximately 0.5 mile between where the aircraft descends into the surveillance volume and where it drops below the volume, it will be illuminated by the 8-ms pulses at intervals averaging about 1.4 s and as short as about 0.6 s. In the other part of that region, it will be illuminated with 5-ms pulses at intervals averaging about 2.6 s. No analysis was done for any of the closed flight tracks, such as 32B5 and others, that pass over this same area and possibly also through the surveillance volume.

The Air Force EED safety criteria are not exceeded for EEDs on the ground at Robins AFB. High pulse power densities will impinge on aircraft on the normal glide slope as they pass downward through the surveillance volume of SEPP. Brief exposures to high power densities are not considered by the Air Force to constitute a hazard (Hovan, 1982).

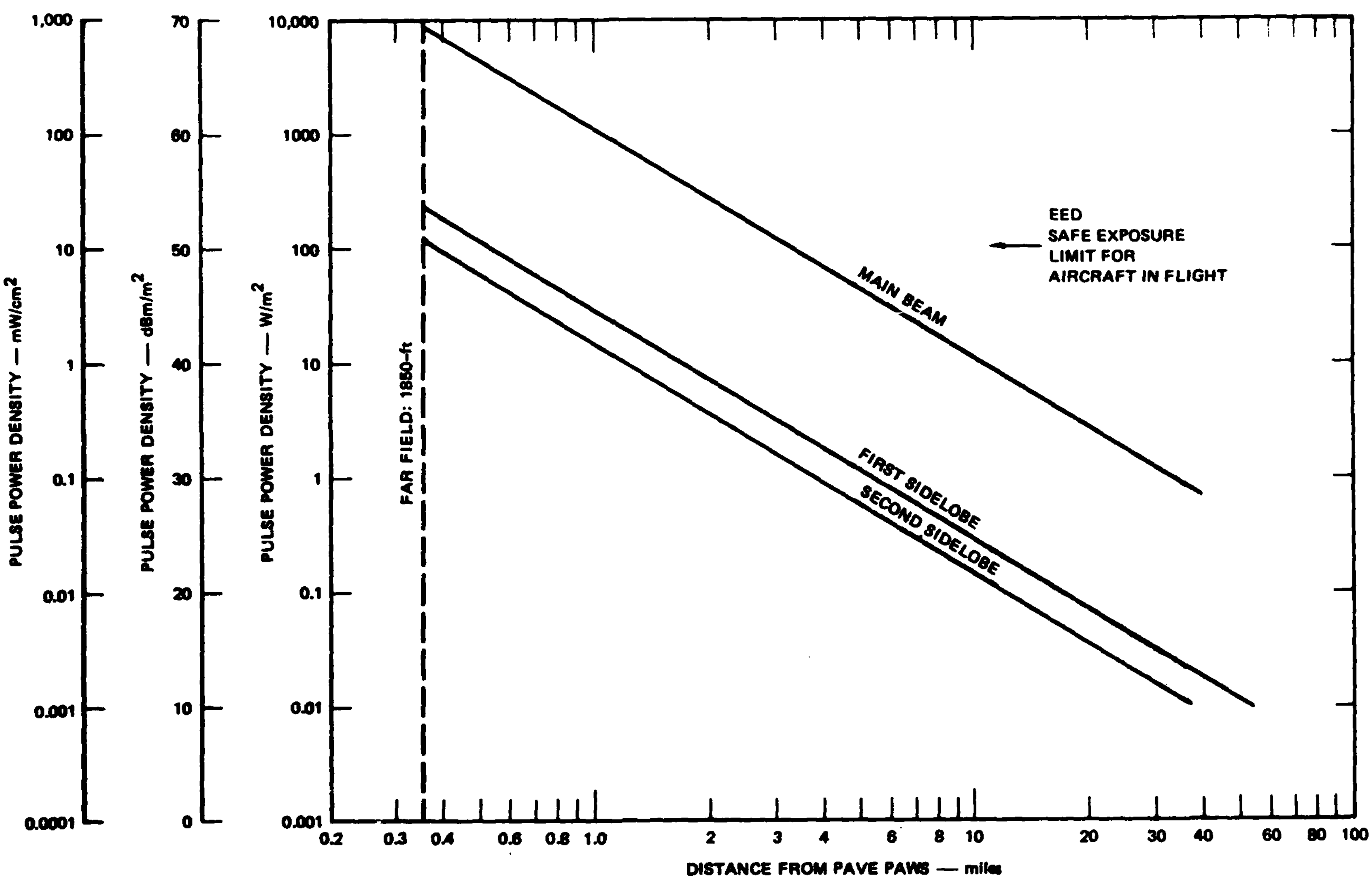


FIGURE C-15 SEPP PULSE POWER DENSITY IN THE SURVEILLANCE VOLUME IN FRONT OF THE RADAR

Table C-17

EED STORAGE AND HANDLING AREAS AT ROBINS AFB

	Distance from PAVE PAWS (miles)	Average Power Density for Safe Exposure (W/m^2)	Estimated Pulse Power Density (W/m^2)
State Highway 247 (closest probable location for transporting EEDs)	0.8	7.5	2.2
5th Street (southernmost likely area for on-base transport of EEDs)	2.2	100	0.0023
SAC Alert Circle, and taxiway (closest point for taxiing aircraft)	3.0	75	0.0012
Explosives handling area (near Taxiway No.2. Class B explosives)	3.3	0.75	0.0010
Ordnance Storage Area (Ocmulgee Dr., adjacent to Taxiway No. 7)	3.6	0.75	0.00086

C.3.2.3.5 EEDs at Moody AFB. There are various types of EEDs at ground-level storage and handling areas and aboard aircraft at this base. Known major storage and handling areas are indicated in Table C-18. The nearest location is the Explosive Ordnance Disposal Area (EOD proficiency range), and all are 1.6 miles or more from the back of the radar so that they are illuminated only by the energy that might be scattered or diffracted in that direction. Estimates of the attenuated pulse power density that would reach those points through the foliage are taken from Figure C-14 and are compared in the table with the most stringent limits applicable. In the case of the EOD proficiency area, used for the disposal of old or outdated ordnance, the estimated pulse power density is below the safe exposure limit by a factor of about 170. At none of the known locations are the pulse power densities expected to even approach the limits. The highway in front of the radar is also listed in the table--as a possible location for EEDs in transit. Portions of this highway may be illuminated by the second sidelobe, although the trees will provide considerable attenuation. Even there, the pulse power density estimate (assuming 10 dB foliage attenuation) is below the safe exposure limit by a factor of more than 3. Average power densities at all locations are much lower than the pulse power densities.

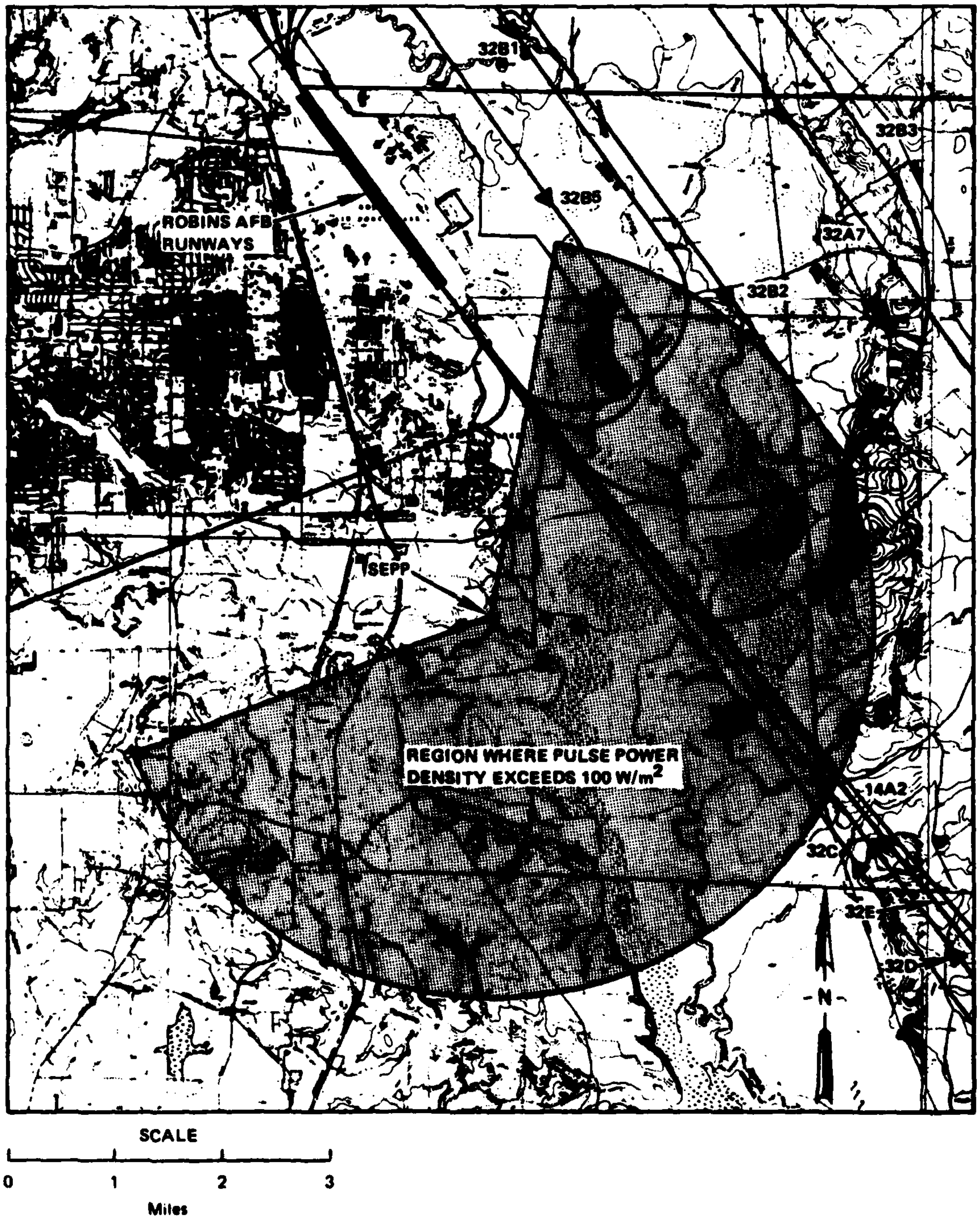


FIGURE C-16 FLIGHT TRACKS AT ROBINS AFB AND PLAN VIEW OF REGION WHERE PAVE PAWS PULSE POWER DENSITY EXCEEDS 100 W/m^2

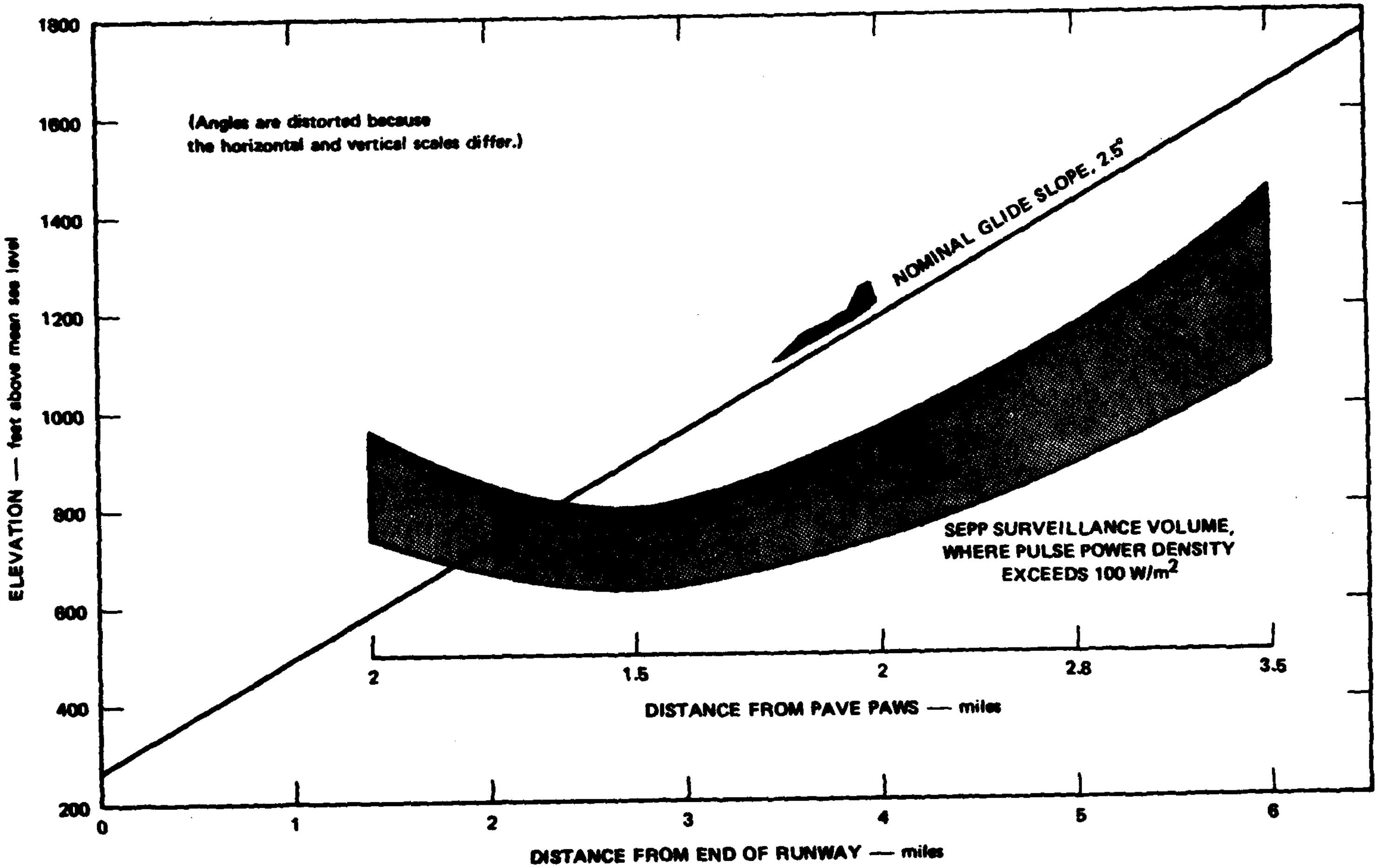


FIGURE C-17 INTERSECTION OF THE NOMINAL GLIDE SLOPE AT ROBINS AFB WITH THE SEPP SURVEILLANCE VOLUME

Table C-18

EED STORAGE AND HANDLING AREAS AT MOODY AFB

	Distance from PAVE PAWS (miles)	Average Power Density for Safe Exposure (W/m^2)	Estimated Pulse Power Density (W/m^2)
US Route 221 (closest probable location for transporting EEDs)	0.8	7.5	2.2
Closest runway (closest point for taxiing aircraft)	2.6	75	0.0017
Explosives handling area (EOD Proficiency Range)	1.6	0.75	0.0044
Ordnance Storage Area (at the end of Burma Rd.)	2.1	0.75	0.0026
South Arm/Disarm Pad (near the south end of the runway)	2.8	0.75	0.0014

According to the Moody AICUZ report, the principal aircraft that operate out of Moody AFB are F-4E, F-4D, T-37, and T-38 aircraft (USAF, 1981). The F-4 aircraft uses the runway and base facilities by far the most, for purposes of advanced training and ordnance delivery training. It is equipped with EEDs for release of external fuel tanks, chaff, and externally carried weapons.

As with SEPP at Robins AFB, 5-ms and 8-ms pulses with pulse power density of 100 W/m^2 will occur in the surveillance volume within about 3.5 miles of the radar. Figure C-18 shows the flight tracks for Moody AFB, as well as a plan view of that high power density portion of the SEPP surveillance volume. Figure C-19 is a vertical-plane cross section of flight track 36DR, frequently used for landing. The figure demonstrates that aircraft on a nominal 2.5-degree glide slope will pass at least 100 ft beneath the surveillance volume in the high pulse-power-density region.

Figure C-20 is a vertical-plane cross section of flight track 36BR between the points A and B of Figure C-18. At a standard altitude of 1,300 ft for this track, the aircraft is far above the surveillance volume as it passes about a mile in front of the radar. Near points A and B, the beam is high enough to illuminate the aircraft briefly with

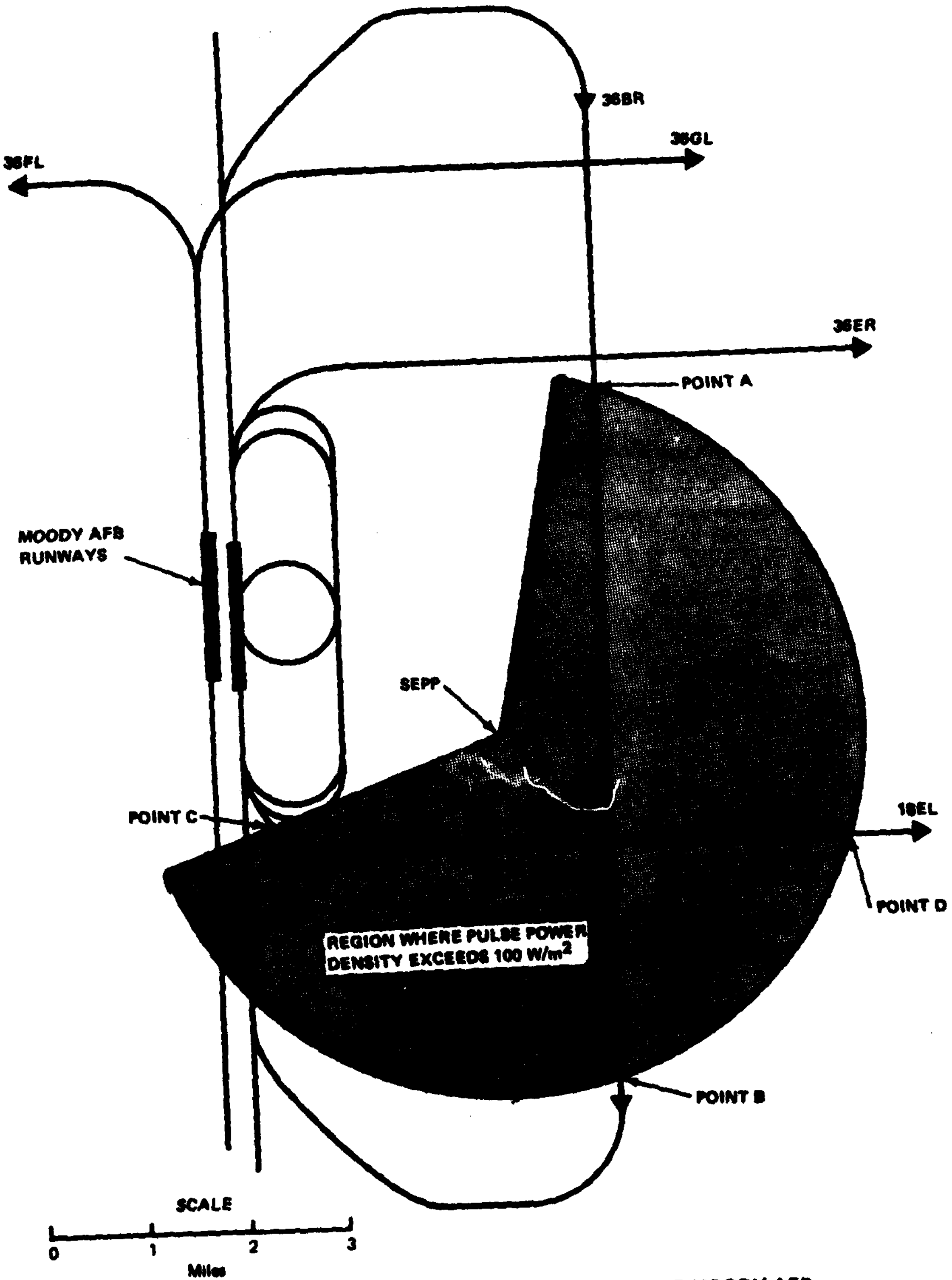


FIGURE C-18 PLAN VIEW OF FLIGHT TRACKS AT MOODY AFB AND PART OF SEPP SURVEILLANCE VOLUME

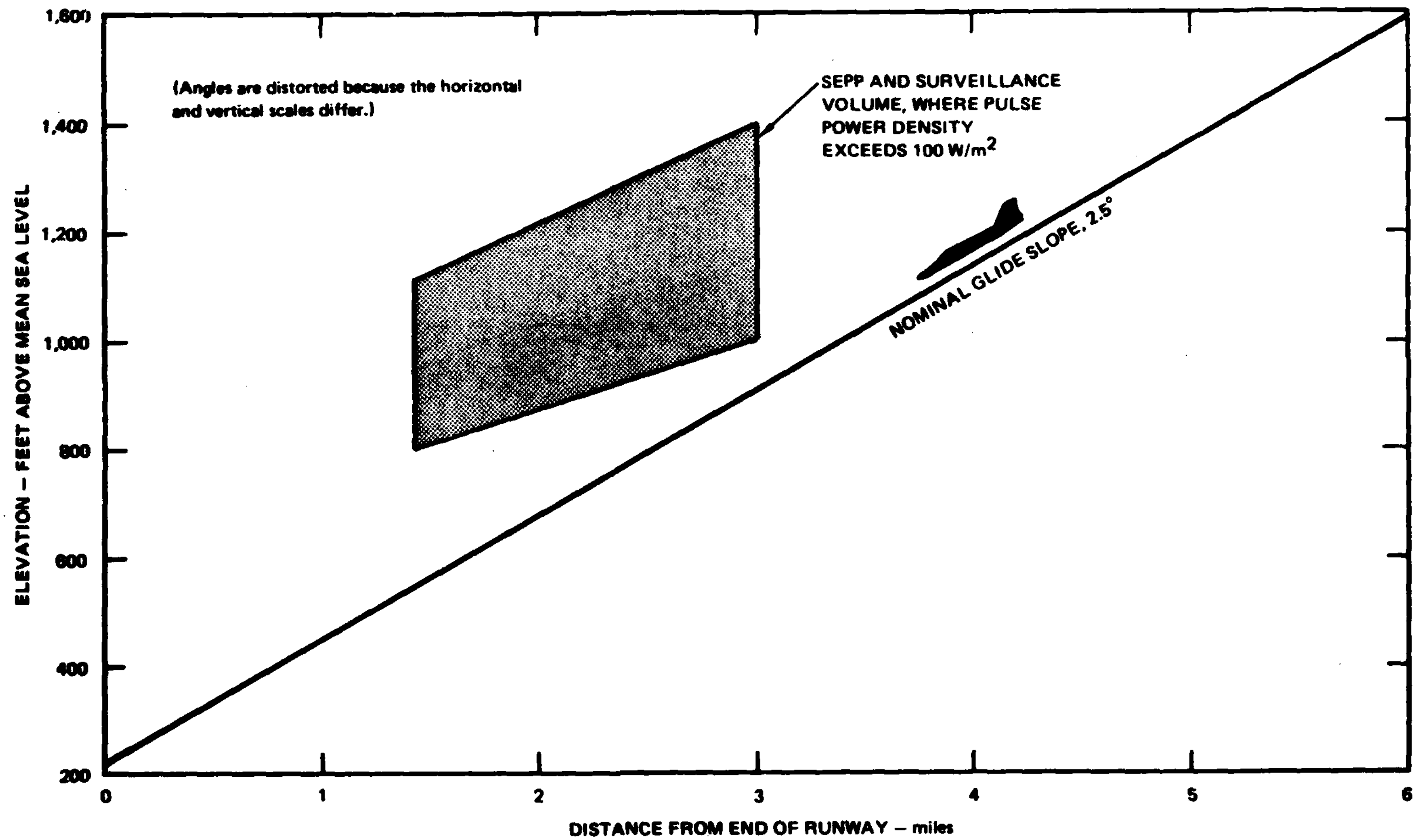


FIGURE C-19 THE NOMINAL GLIDE SLOPE AT MOODY AFB PASSING UNDER THE REGION WHERE PULSE POWER DENSITY EXCEEDS 100 W/m^2

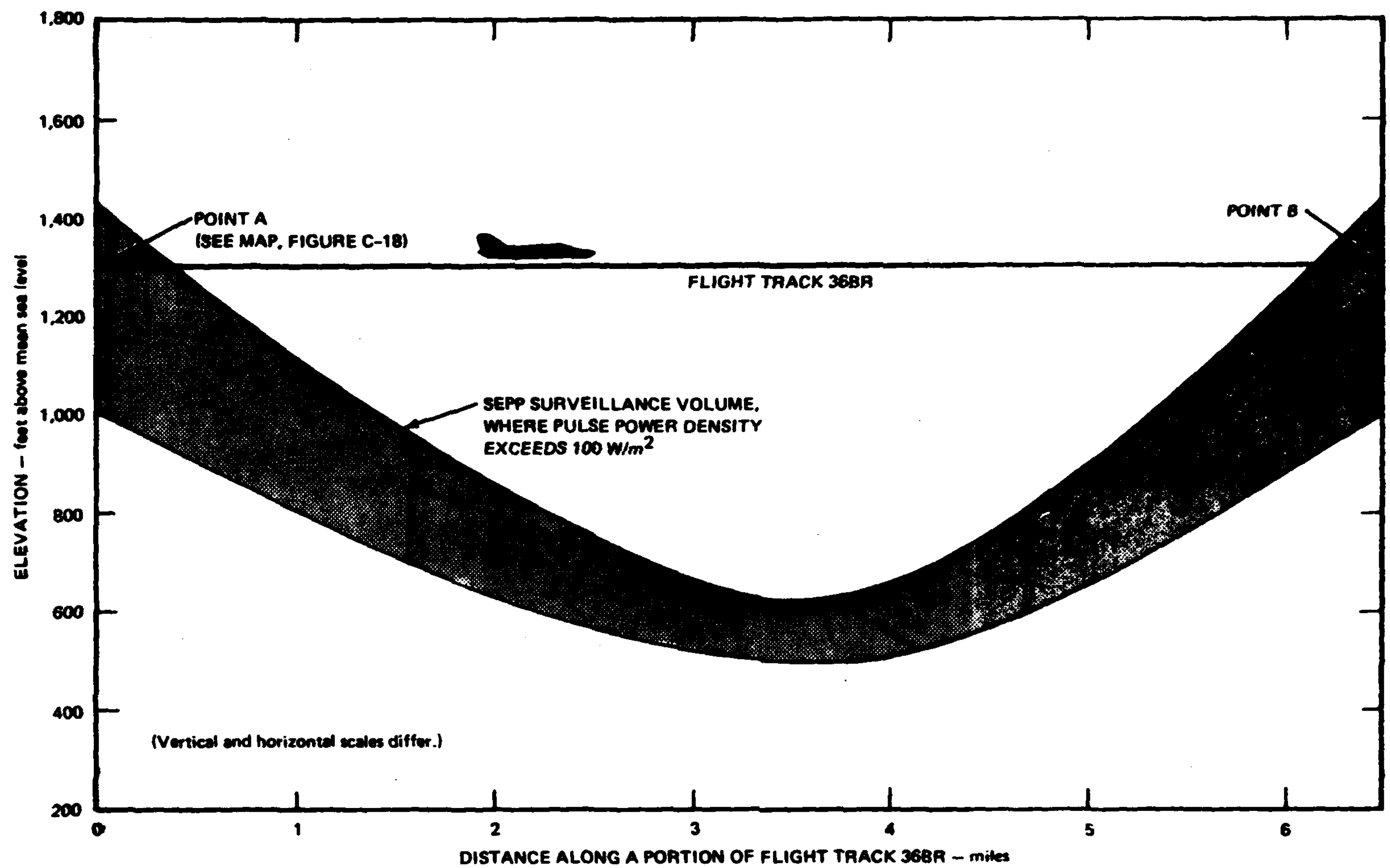


FIGURE C-20 FLIGHT TRACK 36BR—GENERALLY ABOVE THE SURVEILLANCE VOLUME

pulses at a level of about 100 W/m^2. Near point A, the aircraft will be illuminated with 8-ms pulses from the SEPP's east face at intervals averaging about 1.4 s, but as short as 0.6 s. Near point B, illumination is by 5-ms pulses from the SEPP's south face at intervals averaging about 5 s. The plane's speed determines the amount of time it spends in these regions and therefore the number of times it would be illuminated.

The departure flight track 18EL was also considered, between the points C and D on Figure C-18. However, departing aircraft are already at an altitude of about 1,800 ft at point C--400 ft above the top of the surveillance volume there. Thus, aircraft on that track are, at all times, well above the SEPP surveillance volume where pulse levels would exceed 100 W/m^2.

EEDs on the ground at Moody AFB are not illuminated by fields that exceed the Air Force EED safety criteria. Most standard flight tracks at Moody AFB are either behind the SEPP or else they are above or below the SEPP surveillance volume in the region where the pulse power density is greater than 100 W/m^2. However, flight track 36BR passes through that region near points A and B. Brief exposures to high power densities are not considered by the Air Force to constitute a hazard (Hovan, 1982).

When the EIS for the PAVE PAWS at Beale AFB was prepared, it was believed that 20-mm ammunition was particularly susceptible to electromagnetic fields and that a maximum pulse power density of 0.75 W/m^2 was appropriate for handling 20-mm ammunition. Officers of the 347th C-18 Tactical Fighter Wing at Moody AFB have identified 20-mm ammunition as part of the electrically fired ordnance on the F-4 aircraft (Mulvihill, 1982; Lavender, 1982). Neither the 1978 edition of AF 127-100 nor the current revised draft explicitly identifies 20-mm ammunition as hazardous ordnance requiring special power density exposure limits, and so special inquiries were made (Fontana, 1982)

The 20-mm ammunition is categorized with leadless EEDs. The primer is internal to the cartridge, and no external connection is made to the primer until the fighter's M61(A1) cannon is armed, which is done in flight; further, there is no wiring present during installation that could form a resonant antenna (Fontana, 1982). Hence, the criteria for this ammunition is that applied to leadless EEDs in their original shipping configuration and containers. (Normally during handling and installation, leadless EEDs are classified as "EEDs in Exposed Condition" so that the most stringent safe exposure limits would apply.) According to Table 6-1 of the new draft of AF Regulation 127-100 (USAF, 1978), a recommended maximum power density is "Not Applicable" for the typical leadless EED. From this same table, the minimum safe separation distance from any RF emitter is given as 10 ft. The AF Explosive Safety Branch, at Norton AFB, confirmed the appropriateness of both of these table entries (Fontana, 1982). No maximum power density level was established because the primer is inside the cartridge and there are no external leads. The rationale for the minimum 10-ft separation is simply that leadless EEDs should neither touch (nor be placed on) active transmitting

equipment. During this investigation, it was determined that stray RF fields have never been known to cause an accidental firing of 20-mm ammunition.

It appears that PAVE PAWS presents no particular radiofrequency hazard for the fighters at Moody AFB and their 20-mm ammunition.

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